VOL. 99 • NO. 1 • JAN 2018

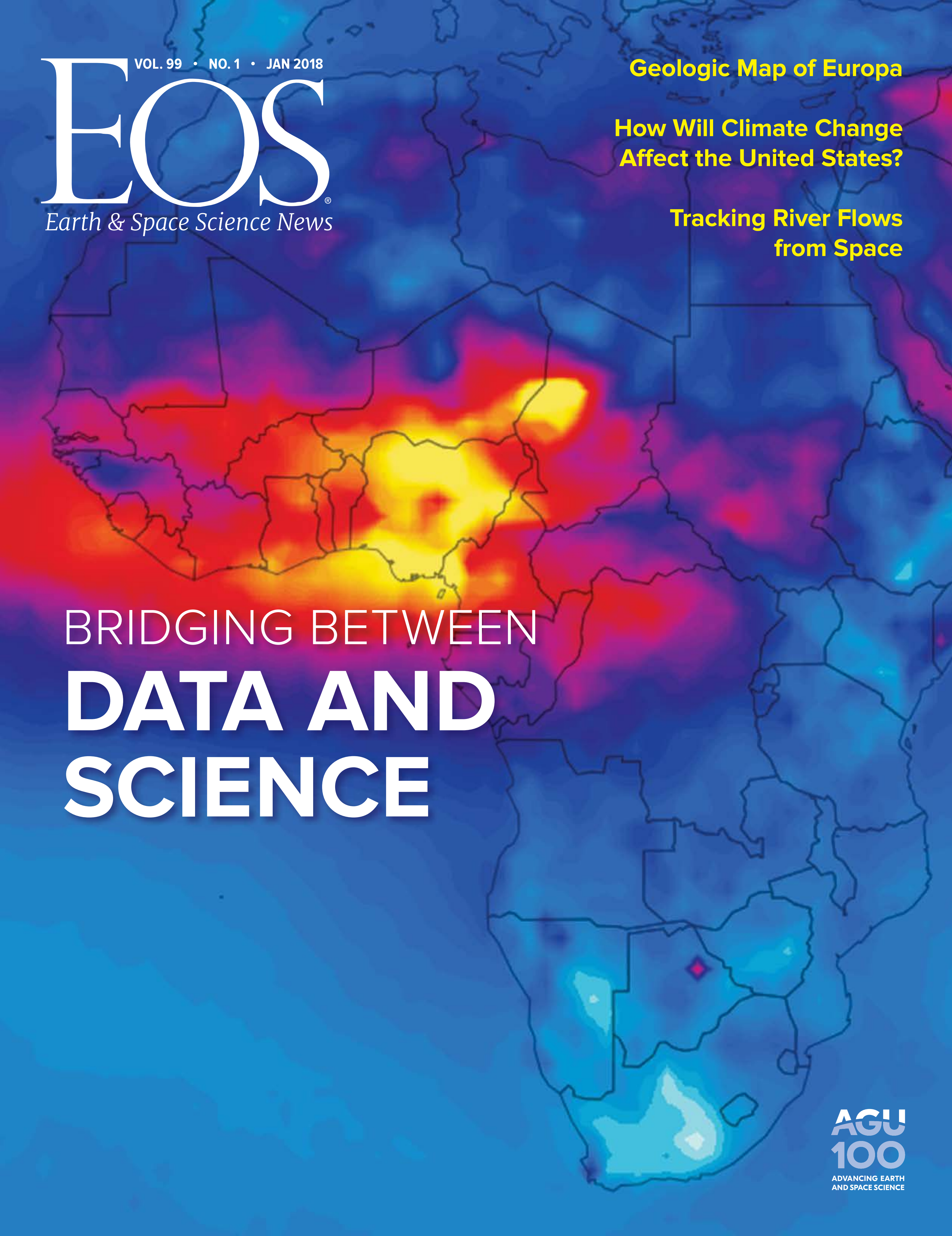
EOS

Earth & Space Science News

Geologic Map of Europa

How Will Climate Change Affect the United States?

Tracking River Flows from Space



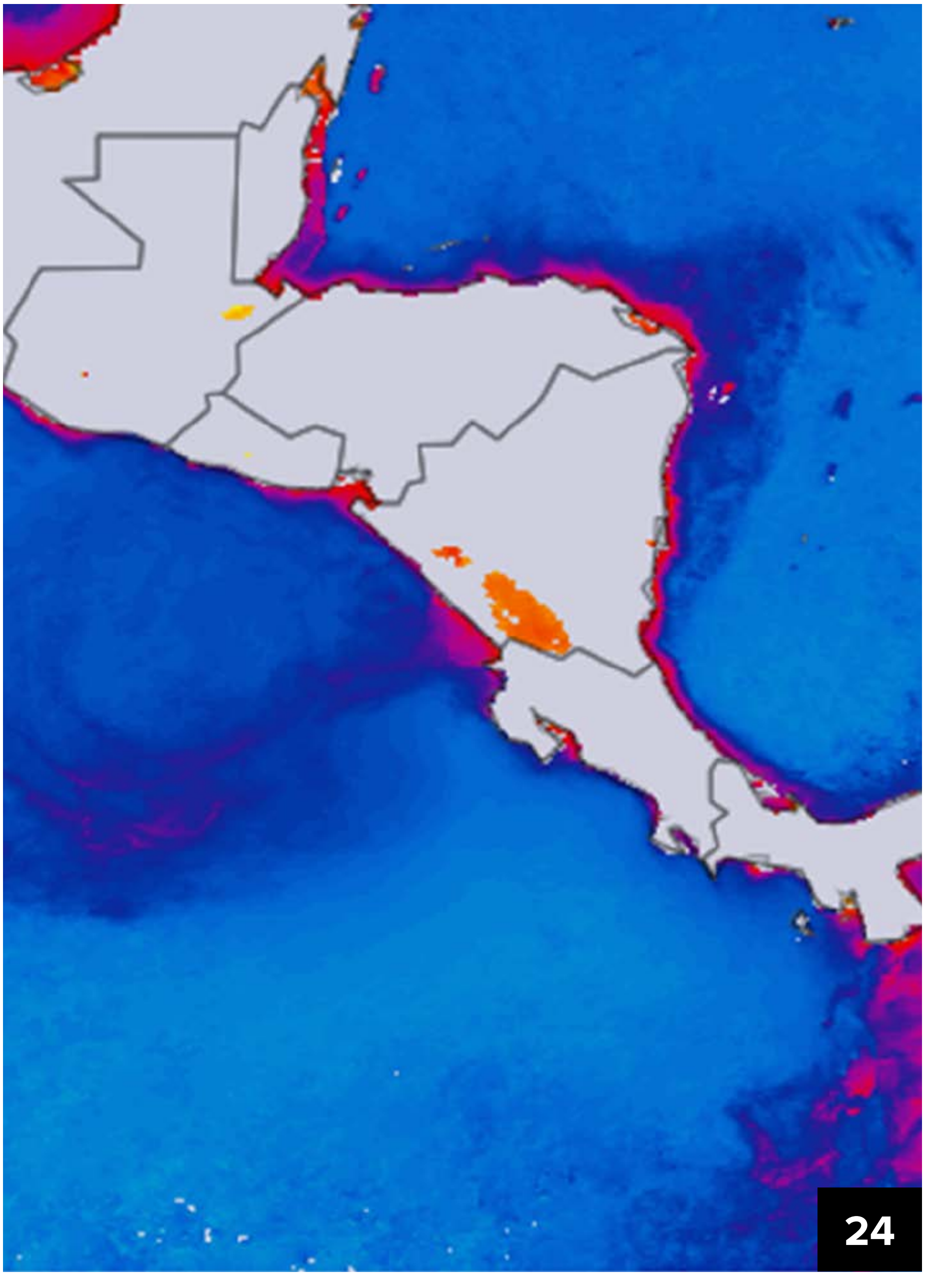
BRIDGING BETWEEN DATA AND SCIENCE

AGU 100

ADVANCING EARTH AND SPACE SCIENCE


2018
HONORS
AGU100 ADVANCING EARTH AND SPACE SCIENCE
Recognize a colleague, mentor, peer or student for their achievements and contributions to the Earth and space sciences.
• Union Medals • Union Fellowship • Union Prizes
• Union Awards • Sections Awards and Lectures
Nominations Open 15 January
honors.agu.org

JANUARY 2018
VOLUME 99, ISSUE 1



COVER

Giovanni: The Bridge Between Data and Science

A Web-based tool provides a way to access, visualize, and explore many of NASA's Earth science data sets.

FEATURE

How Will Climate Change Affect the United States in Decades to Come?

A new U.S. government report shows that climate is changing and that human activities will lead to many more changes. These changes will affect sea levels, hurricane frequency, wildfires, and more.

PROJECT UPDATE

Tracking River Flows from Space

Satellite observations, combined with algorithms borrowed from river engineering, could fill large gaps in our knowledge of global river flows where field data are lacking.

OPINION

12 To Understand Future Solar Activity, One Has to Know the Past

Short-term funding strategies present serious problems for programs like solar activity studies, where observations and analysis span decades or longer.

DEPARTMENTS

45

6

On the Cover

Map of March aerosol optical density over Africa, averaged from 2003 to 2016, generated using NASA's Giovanni data portal. Credit: Giovanni

EOS®

Eos (ISSN 0096-3941) is published monthly by the American Geophysical Union, 2000 Florida Ave., NW, Washington, DC 20009, USA. Periodical Class postage paid at Washington, D. C., and at additional mailing offices. POSTMASTER: Send address changes to Member Service Center, 2000 Florida Ave., NW, Washington, DC 20009, USA.

Member Service Center: 8:00 a.m.–6:00 p.m. Eastern time; Tel: +1-202-462-6900; Fax: +1-202-328-0566; Tel. orders in U.S.: 1-800-966-2481; Email: service@agu.org.

Use AGU's Geophysical Electronic Manuscript Submissions system to submit a manuscript: http://eos-submit.agu.org.

U.S. Weather Alert Systems Must Modernize, Say New Reports

Weather forecasting and hazard prediction capabilities have improved significantly in the past decade, but the United States' emergency alert and warning systems have not kept pace with advancements, according to two new reports from the National Academies of Sciences, Engineering, and Medicine (NASEM). The reports were released on 1 November (http://bit.ly/weather-reports-2017).

Research that improves the accuracy of weather forecasts and hazard prediction must continue, the reports state. However, to make the best use of forecasts, the nation's alert capabilities "will need to evolve and progress as the capabilities of smart phones and other mobile broadband devices improve and newer technologies become available," according to an official summary of one of the reports. The summary adds that "this evolution will need to be informed by both technical research and social and behavioral science research."

Expand the System to New Technologies

One report, titled "Emergency Alert and Warning Systems: Current Knowledge and Future Research Directions," identifies knowledge and coverage gaps in the current alert systems, outlines the potential challenges in building and implementing a new system, and sets a research agenda to improve the nation's alert and warning capabilities by integrating new science and technology.

Social and behavioral science research seeks to understand why people choose to drive in hazardous conditions, like this blizzard, despite receiving accurate weather forecasts and alerts. Two new reports recommend using this research to tailor alert messages so that people are more likely to heed weather warnings. Credit: BanksPhotos/iStock/Getty Images Plus

For example, the current Wireless Emergency Alerts (WEA) system, a part of the Integrated Public Alert and Warning System (IPAWS), leverages the ubiquity of cell phones in modern life. But the system can fail when cellular networks are congested or coverage is unavailable, and it does not use the diverse communication capabilities of smartphones, says the report. It states that social media and private companies, including Facebook, Twitter, and Google, have begun to incorporate hazard warnings and alerts into their platforms, which likely reach more individuals than WEA.

NASEM's Committee on the Future of Emergency Alert and Warning Systems: Research Directions, which wrote the report, suggests that "IPAWS could be augmented so that it draws on a wide variety of data sources, enhances public understanding of emergencies and public response, and uses a wider range of potential technologies and devices for delivering messages." The committee adds that "alerts and warnings that reach people through tools and communication devices they are using and present information in a way they are accustomed to will be the most effective."

Social and Behavioral Sciences Should Guide System Updates

The report on emergency alerts and warning systems proposes an interdisciplinary agenda to incorporate research into social and behavioral sciences that could improve the systems' effectiveness at delivering weather warnings. A separate report, titled "Integrating Social and Behavioral Sciences Within the Weather Enterprise," expands on that agenda.

The report shows how people's knowledge, experiences, perceptions, and attitudes toward severe weather forecasts shape how they respond to potential hazards. The report also highlights the need to integrate expertise in social and behavioral sciences to reduce property damage, injury, and loss of life.

To illustrate this need, the report explains that nearly 6,000 people are killed and more than 445,000 people are injured each year in weather-related vehicle crashes on U.S. roadways despite forecasts, reports, and alerts of hazardous driving conditions. In addition, the report notes that severe weather events with widespread warnings can still result in large-scale loss of life and property damage, as was the case with Hurricane Sandy in 2012 and Hurricanes Harvey, Irma, and Maria in 2017. By knowing how people respond to warnings and why they respond the way they do, scientists could develop a more well informed system that could promote better public safety.

NASEM's Committee on Advancing Social and Behavioral Science Research and Application Within the Weather Enterprise wrote this second report. In it, the committee explains that "an individual's response to a severe weather event may depend on their understanding of the forecast, prior experience with severe weather, concerns about their other family members or property, their capacity to take the recommended protective actions, and numerous other factors."

The report adds that research in social and behavioral sciences "offers great potential not just for improving communications of hazardous weather warnings but also for improving preparedness and mitigation for weather risks, for hazard monitoring, assessment, and forecasting processes, for emergency management and response, and for long-term recovery efforts."

Challenges Ahead

Both reports acknowledge that their proposed modernization efforts may face significant challenges. They explain that an ever changing technological landscape and slow adoption of new technologies mean that an updated system would need to be compatible with new and old technologies simultaneously. The summary of the alert system report also recognizes that "a system that instructs large populations to take a particular action may represent a significant target for spoofing or attacks on service availability" and that security and privacy issues would be paramount.

Nonetheless, the two reports agree that integrating new technologies into the current weather emergency alert system, guided by expertise in social and behavioral sciences, can improve disaster preparedness and mitigation. Together, the reports show that updating alert systems can enhance emergency management and responses, ultimately saving homes and lives and protecting communities from preventable losses.

By **Kimberly M. S. Cartier** (@AstroKimCartier), News Writing and Production Intern

NEWS

Experts Wonder Why Administration Released Tough Climate Report

A sign urging action to combat human-induced climate change. Scientists and policy experts speculated as to why the Trump administration issued a tough climate report last November. Credit: Tobias Titz/Getty Images

Although the Trump administration is busy rolling back Obama-era climate policies, it also allowed the release in early November of a major report that runs counter to the administration's own position on climate change. Scientists and policy experts told *Eos* that they think the administration allowed the report to be released on 3 November without political interference to avoid potential controversy about censorship.

"The Trump White House staff clearly judged that the firestorm if they tried to delay or suppress the report release would be greater than that from the findings themselves, even though the report utterly contradicts nearly all Trump administration climate science and policy statements," Paul Bledsoe, who helped release the first national climate assessment in 2000 while serving in the Clinton administration as communications director of the White House Climate Change Task Force, told *Eos*. Bledsoe currently is a lecturer at American University's Center for Environmental Policy in Washington, D. C.

The Climate Science Special Report (http://bit.ly/climate-report-2017), prepared by the U.S. Global Change Research Program (USGCRP), which comprises 13 federal agencies, concludes that "it is *extremely likely* that human activities, especially emissions of greenhouse gases, are the dominant cause of the observed warming since the mid-20th century." The report—volume 1 of the Fourth National Climate Assessment, a quadrennial report mandated by the Global Change Research Act of 1990—also summarizes climate-related weather extremes and states with high confidence that "the likely contributions of natural forcing and internal variability to global temperature change over that period are minor." National Oceanic and Atmospheric Administration scientist and contributing lead author David Fahey said at a 3 November briefing that despite fears of censorship, "there has been no political interference in the scientific messages from this report."

In response to the report, which all USGCRP agencies and the White House Office of Science and Technology Policy (OSTP) reportedly signed off on, White House deputy assistant to the president Raj Shah provided a statement that seemed to downplay the report's findings. He said, "The climate has changed and is always changing. As [the report] states, the magnitude of future climate change depends significantly on 'remaining uncertainty in the sensitivity of Earth's climate to [greenhouse gas] emissions.'"

A Calculated Response to Avoid Controversy?

Rosina Bierbaum, acting OSTP director in 2001 during the George W. Bush administration, told Eos that "the political leadership at OSTP made it clear to the USGCRP early on in the Trump administration that they were aware of the problems the Bush administration had run into over censored climate science, and had no interest in interfering with the science."

Bierbaum, a professor at and former dean of the University of Michigan's School for Environment and Sustainability, called the report "impeccably reviewed" and said that Shah's statement about the report is "disingenuous" and "obfuscates the fact that uncertainty about future emissions will dominate the long-term climate outcomes." Bierbaum highlighted report language that states that "most of the difference between present and future climates will be determined by choices that society makes today and over the next few decades."

In releasing this "relatively ominous" report in its current form, the administration may have calculated that "for the most part people don't particularly care about these issues in their political world," energy expert Frank Maisano told *Eos*. Climate change "continues to be a low-priority issue, and if you would have stopped [the report], it would have been a larger story than letting it go forward."

The report also doesn't say anything about policy to address climate change, added Maisano. Maisano is a principal at the Policy Resolution Group at Bracewell, a Washington, D. C.–based law and government relations firm serving the oil and gas, power, and other industries.

Inconvenient Report?

The report's conclusion, which reaffirms that climate change is real, human caused, and an increasing threat, "is inconvenient for the current administration which is led by a climate change–denying president who has appointed climate change contrarians and fossil fuel industry lobbyists to key cabinet-level positions," Michael Mann, a professor of atmospheric science at Pennsylvania State University in University Park, told *Eos*.

"It is sad that the administration has already tried to dismiss the findings of the report with denialist talking points like 'climate always changes,'" he said.

By **Randy Showstack** (@RandyShowstack), Staff Writer

Editor's Note: For details about the report, see the feature article beginning on page 18.

Signatures of Dinosaur Poop Found in Cretaceous Coal Seams

Carnivorous dinosaurs may get all the attention, but their plant-eating kin likely played an important role in boosting ecosystem health by distributing nutrients, a new study shows.

That role involves their poop. Christopher Doughty, an environmental scientist at Northern Arizona University in Flagstaff, has investigated the long-held hypothesis that large herbivores—brachiosaurs, triceratops, and the like—transported nutrients by defecating significant distances from where they ingested their food.

Doughty compared hundreds of coal deposits from the herbivore-rich Cretaceous period with coal samples from the older Pennsylvanian subperiod, which lacked large, four-legged herbivores. His analysis showed that coals from the Cretaceous have significantly higher levels of nutrients than the Pennsylvanian subperiod coals.

The finding, published 16 October 2017 in *Nature Ecology and Evolution,* suggests that the many herbivorous dinosaurs alive during the Cretaceous period were effective at spreading plant-important nutrients far and wide (http://bit.ly/doughty-2017). "By redistributing these elements, herbivores were making the whole ecosystem more productive," Doughty said.

> "Large herbivores are critical for changing the large-scale distribution of nutrients."

From Dung to Coal

Large animals produce a lot of dung, but that's not really why they're good at distributing nutrients, said Doughty. "The key is that large animals move these elements across landscapes."

By making assumptions about dinosaur movements, feeding patterns, and biology, based on the attributes of large modern-day mammals, Doughty estimated that an herbivore living during the Cretaceous walked about 7–16 kilometers between ingesting a meal and defecating. That's a long way, he said, far enough for an animal to travel away from the presumably nutrient-rich area in which it consumed its food and into a potentially nutrient poor area.

If these estimations reflect truth, Doughty reasoned, records of plant material from time periods with many large herbivores ought to be more enriched in nutrients—and more evenly so—than records from eras lacking large herbivores. That's simply because plants growing in ecosystems with higher levels of nutrients tend to take those nutrients into their tissues.

But where could he find past records of plant material? The answer, Doughty realized, lay with coal: Over time, buried plant material forms peat and then coal. This coal could reveal clues about defecating behaviors of dinosaurs, Doughty figured.

A computer rendering of a Brachiosaurus. *Extinct herbivores like the brachiosaurs likely helped distribute nutrients through their poop. Credit: Roger Harris/Science Photo Library/Getty Images*

Thousands of Coal Samples

Doughty used an online database called COALQUAL maintained by the U.S. Geological Survey to extract chemical measurements from more than 600 Cretaceous-era coal deposits and nearly 5,000 Pennsylvanian subperiod coal deposits, distributed in the western United States and in the Appalachian region, respectively. His analysis showed that levels of calcium, magnesium, phosphorus, and sulfur were significantly higher—by 136%, on average—and less variable in the Cretaceous coals than in the Pennsylvanian subperiod coals.

To check that weathering processes like erosion and precipitation weren't causing the discrepancy, Doughty extracted data about aluminum, an element toxic to plants and therefore not incorporated into their tissues, from COALQUAL. The difference in aluminum concentration between the Cretaceous and Pennsylvanian subperiod coal samples was small and not statistically significant, which suggests that a change in weathering patterns can't explain the difference in nutrient levels.

Doughty concluded that the heightened and steadier levels of plant-important nutrients in the Cretaceous period coals were due to plant material being dispersed by dinosaur poop.

In other words, the poop from trekking dinosaurs served both to enrich plant material and to equalize nutrients across plant communities represented by the coal seams. In this way, nutrient-poor areas likely gained minerals needed to sustain healthy ecosystems, Doughty explained.

Innate differences in nutrient uptake among plants living during the two time periods might call into question this hypothesis, Doughty acknowledged. But recent research has found that the types of plants common in the Pennsylvanian subperiod contained higher levels of calcium, magnesium, and phosphorus than plants widespread in the Cretaceous. That finding suggests that herbivorous dinosaurs might have had an even larger effect than originally estimated, Doughty noted.

Loads to Digest

This work "strongly suggests that large herbivores are critical for changing the large-scale distribution of nutrients," said Hillary Young, an ecologist at the University of California, Santa Barbara, who was not involved in the research.

But the modern era—the Anthropocene, literally, the "age of man"—simply doesn't have a lot of large, free-roaming animals left to distribute nutrients, Doughty explained. So if we lose these animals, like hippos and elephants, ecosystems could suffer for a very long time, he added.

"Large animals are playing a critical role in ecosystems that can't be replicated in other ways," Doughty said. "We need to start thinking about preserving ecosystems with large animals."

By **Katherine Kornei** (email: hobbies4kk@gmail.com; @katherinekornei), Freelance Science Journalist

Pollution over Southeast Asia May Threaten Ozone Health

A rise in emissions of short-lived chlorine-based chemicals over the past decade has created a possible new threat to the health of Earth's protective, yet fragile, ozone layer.

A recent study shows that human-made emissions of short-lived chlorocarbons, chemicals not regulated by the internationally ratified Montreal Protocol, have increased in a region of the atmosphere where air from the surface is thought to get rapidly pumped into the upper troposphere. These chlorocarbons, once further lofted into the stratosphere, may eat away at stratospheric ozone.

Just where are these chlorocarbons coming from? Industrial and agricultural processes in Southeast Asia, particularly in China, are the sources, explained David Oram, a research fellow at the National Centre for Atmospheric Science at the University of East Anglia in Norwich, U.K. Oram and his team published these results in *Atmospheric Chemistry and Physics* on 12 October 2017 (http://bit.ly/oram-2017).

Tracking Pollutants

Scientists have noticed that atmospheric concentrations of short-lived chlorocarbons, particularly 1,2-dichloroethane and dichloromethane, have been on the rise worldwide since 2003. This increase was a surprise to the scientific community, as it came after nearly a decade of slowly declining concentrations. Oram's team suspected that the sharp rise in pollution could be coming from nations with rapidly developing industries, and they sought to test that.

The researchers collected air samples at surface-level research stations in Malaysia and Taiwan. Chemical analysis of those samples revealed 1,2-dichloroethane and dichloromethane concentrations more than 20 times higher than expected from previous reports.

These levels were concerning, Oram explained. Short-lived chlorocarbons were recently recognized as some of the most effective ozone depleters.

Oram's team next sought to pinpoint just where these pollutants were coming from and where they might be going. To do so, it collected additional air samples at altitudes of 10–12 kilometers across Southeast Asia using Europe's specialty aircraft known as Civil Aircraft for the Regular Investigation of the Atmosphere Based on an Instrument Container (CARIBIC). The aircraft is designed to take high-altitude atmospheric samples. The team's upper troposphere samples came from several CARIBIC flights spanning Southeast Asia from Kuala Lumpur, Malaysia, to as far west as Karachi, Pakistan.

Within those high-altitude air samples, the team found tropospheric concentrations of dichloromethane and 1,2-dichloroethane up to 3 times higher than expected and "in a region where air is known to be transferred into the stratosphere," Oram said.

Water vapor and smoke billow from the cooling tower and smokestacks of this steel factory in Hebei, China, a province dominated by industry. Factories here, along with other emission sources, produce chlorocarbon pollutants that may end up further damaging the ozone layer. Credit: Kevin Frayer/Getty Images News/Getty Images Plus

For the last piece of the puzzle—where the pollutants originated—the researchers used computer simulations to backtrack where air over Malaysia is pulled from. The simulations indicated that the pollutants were likely emitted 1–2 weeks earlier in continental Southeast Asia.

The team then compared the predicted emission dates and locations to publicly reported industrial emissions data from the region. These data allowed them to quantitatively link the significantly increased chlorine concentrations to industrial growth in China from 2000 onward.

Dichloromethane and 1,2-dichloroethane are frequently used in human-controlled processes like paint stripping, agricultural foam blowing, solvent and degreasing applications, and polyvinyl chloride (PVC) manufacturing. The researchers estimated that China may be responsible for around 50%–60% of current global emissions of these two chlorocarbons.

Holes in the Montreal Protocol

The Montreal Protocol on Substances That Deplete the Ozone Layer, which took effect on 1 January 1989, has been successful in making large reductions in the emission of chemicals that damage stratospheric ozone. Research conducted in the past decade has shown that the ozone layer has begun to heal in the time since the Montreal Protocol began regulating emissions of anthropogenic halogen-based chemicals containing fluorine, chlorine, or bromine, which are the most damaging to ozone.

However, the Montreal Protocol does not regulate the emission of short-lived halocarbons because in small doses they have a negligible effect on the health of the ozone layer compared with longer-lived species. At the time the Montreal Protocol took effect, emissions of the chlorocarbons examined by Oram's team were low enough that scientists did not think they caused much damage in their shorter than 6-month life span.

But now this research calls into question past assumptions. Could high emissions of short-lived chlorocarbons over Asia have lasting consequences? At the very least, "these chemicals are slowing down the decline in atmospheric chlorine abundance," said Oram. From 2008 to 2012, chlorine concentrations declined by an average of 0.4% per year, slower than the 0.6% decline from 2002 to 2004.

Geography Matters

The researchers also found that the short-lived chlorocarbons' potential effect on ozone largely depends on where those compounds originate geographically. Put a different way, Asia's chlorocarbon emissions occurred in just the right spot for a quick trip to the stratosphere.

Oram explained that in areas of the globe that do not have quick atmospheric pathways from the surface to the stratosphere, short-

lived chlorocarbons can do little damage. But scientists have long suspected that atmospheric patterns created fast tracks to the stratosphere above the Indian subcontinent and western Pacific Ocean, tropical regions with strong atmospheric convection and vertical uplift.

Chlorocarbons that find their way to these fast tracks, Oram added, could reach the upper troposphere in approximately 10 days, well within the chemicals' life spans. By contrast, "emissions of short-lived compounds in, for example, North America or Europe are potentially less harmful, as it typically takes air much longer to find its way to the tropics," he explained.

A Short-Lived Threat or Nonexistent?

Because the chemicals are mostly anthropogenic, the researchers argue that humans can and should begin to control production of short-lived chlorocarbons and their emission into the atmosphere, especially in areas like Southeast Asia that have a mechanism for rapid stratospheric transport.

"Short-lived chlorocarbons have been generally overlooked in terms of ozone loss in recent years," said University College London atmospheric chemist David Rowley, who was not involved in the study. "This was wrong."

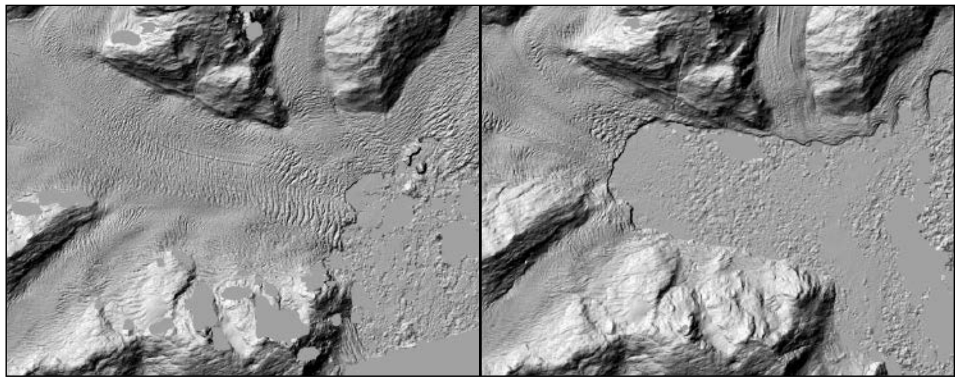
But although the research shows that short-lived chlorocarbons make it to an upper tropospheric region that pulls air into the stratosphere, the fate of these chemicals in the stratosphere is unknown. As a result, some scientists are not convinced that these chlorocarbons pose much of a threat once the chemicals actually reach the stratosphere.

"The measurements report dichloromethane at an altitude of 10–12 kilometers—this is still the troposphere," Susan Strahan told *BBC News* (https://bit.ly/ozone-threat). Strahan researches atmospheric transport processes at NASA Goddard Space Flight Center in Greenbelt, Md., and also did not participate in this research. "In the additional weeks required to travel to the lower stratosphere, which is above 16 kilometers, even more of the compound will be destroyed."

Still, Oram believes that their results "are highlighting a gap in the Montreal Protocol that may need to be addressed in the future, particularly if atmospheric concentrations continue to rise." He believes that "these chemicals should potentially be considered for inclusion in the list of ozone-depleting substances controlled by the Montreal Protocol."

By **Kimberly M. S. Cartier** (@AstroKimCartier), News Writing and Production Intern

Map Provides High-Resolution Look at Nearly Entire Arctic Region



Two ArcticDEM images from a time series showing retreat of the West Branch of the Columbia Glacier in Alaska from 2010 to 2015. The left image dates from 5 September 2010, the right image from 17 January 2015. Credit: Paul Morin, PGC

"The Arctic, before we started, was one of the most poorly mapped places on Earth. It's not anymore," said Paul Morin, a co-principal investigator of the ArcticDEM initiative, which last fall released high-resolution digital elevation models (DEM) of 97.4% of the region. With this release, "we have a uniform product at 2-meter [resolution]" for all the land area north of 60°N latitude, plus those parts of Alaska, Greenland, and Russia's Kamchatka Peninsula that are south of that point.

The public-private initiative plans to fill in the gaps with a final release in May 2018, according to Morin, director of the Polar Geospatial Center (PGC) at the University of Minnesota.

The initiative, which has produced a 3-D digital representation of terrain surface, is an important tool for studying, understanding, and making decisions about the Arctic, including resources, natural hazards, and infrastructure, scientists and environmental managers told *Eos*. It is "a game changer for high-latitude science and modeling," said Laurence Smith, professor of geography at the University of California, Los Angeles.

Released on 6 September, the publicly available ArcticDEM incorporates satellite-acquired imagery, high-performance computing, and open-source photogrammetry software to stitch together a terrain model that governments, commercial entities, and the academic community could find useful for many applications (http://bit.ly/ArcticDEM-2017).

The ArcticDEM release consists of two products, Morin told *Eos*. One is a time-stamped, 2-meter-resolution collection of overlapping DEMs of the Arctic, with each DEM having the date and time associated with it. The other is a 5-meter-resolution DEM product, which is not time stamped, of the entire region. The products build on earlier ArcticDEM versions by adding 32% more terrain data, including sizable portions of Russia and Scandinavia.

Temporal Aspect of Topography

The products provide two significant advances, according to Morin. The first is that the resolution for just about the entire Arctic is much higher than in other models. For instance, compared with the U.S.-Japanese Advanced Spaceborne Thermal Emission and Reflection Radiometer's (ASTER) Global Digital Elevation Model (GDEM), which came out with updated versions in 2011 and 2016, the 5-meter ArcticDEM has 36 times the resolution. ASTER's GDEM has 30-meter pixels, whereas the 2-meter ArcticDEM has 225 times greater resolution.

The second major advance, Morin said, is the time element incorporated into the 2-meter-resolution DEMs obtained from multiple satellite passes over regions. This allows for a comparison of topography over time in the rapidly changing Arctic region, including changes in glaciers and permafrost, he said. The difference between the 5- and 2-meter-resolution products is "the

difference between a map and a time series of measurements," he said. Morin added that the 5-meter-resolution product is beneficial for providing a view of an entire watershed or other large region, whereas the time-stamped 2-meter-resolution product is more useful for studies of smaller areas over time.

"Probably the biggest leap forward here for science is that we've proven that topography can be produced continuously," Morin said. This means that whenever the Sun is at least 7° above the horizon, satellites are gathering stereo imagery that then gets processed and released in short order, he explained. Every year, about 75% of the entire Arctic gets re-imaged, he said. For some high-priority areas, such as outlet glaciers in Greenland, the re-imaging happens more frequently. Satellites collect each stereo image as a pair of mono images taken at specific, known angles.

Previous DEM production projects were "one-offs," Morin noted. A large mapping effort would produce a DEM of a region like Alaska with the intention of not repeating the mapping for an extended period of time, he noted.

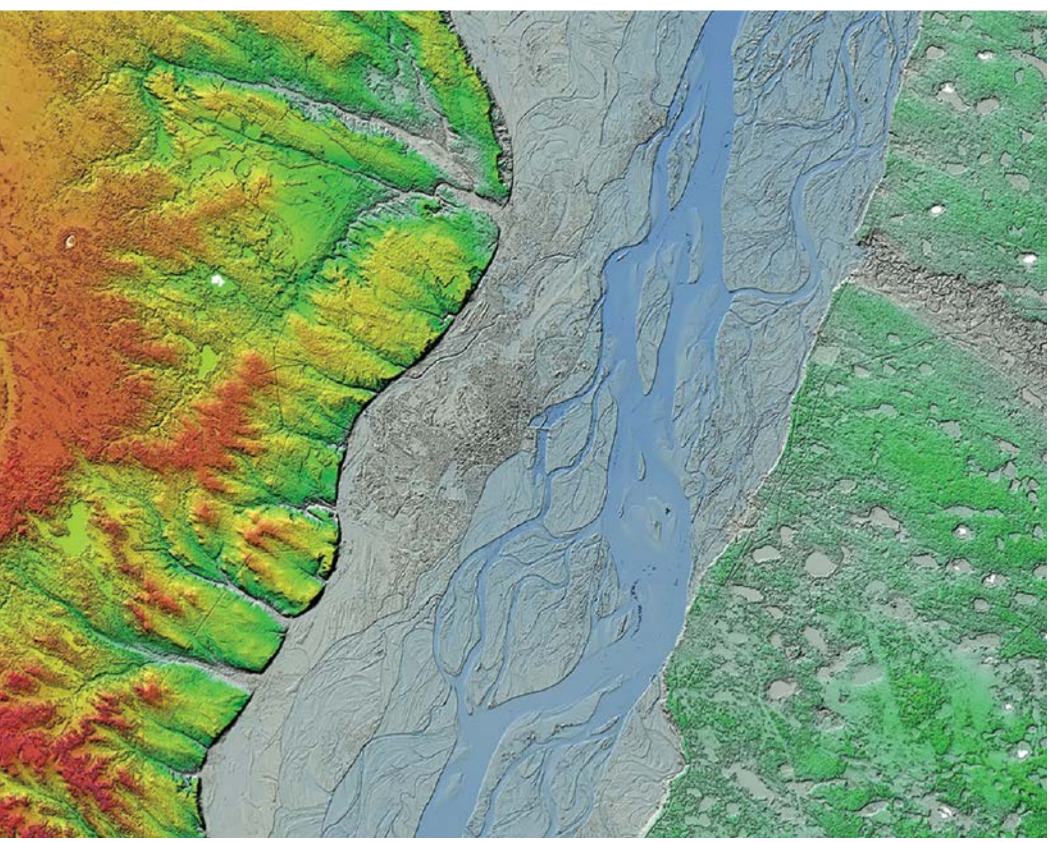
Ragnar Heidar Thrastarson, geographic information system coordinator for the Icelandic Meteorological Office, said, "Previously, we thought of DEMs as a fixed spatial entity that needed to be collected once and then maybe again in 20 years or so. But there are a lot of natural phenomena that change faster than that," he told *Eos*. The new temporal aspect of ArcticDEM "is a huge benefit" for modeling those and subsequent changes in glaciated areas, he said.

Public–Private Partnership

The U.S. National Geospatial-Intelligence Agency (NGA) and the National Science Foundation (NSF) have supported the initiative, which grew out of a January 2015 executive order from then president Barack Obama. The four satellites used for collecting imagery—Worldview-1, -2, and -3 as well as GeoEye-1—are all owned by DigitalGlobe and licensed by NGA, which provides the imagery for the initiative.

NSF is providing $2.5 million through its Directorate for Geosciences. In addition, the NSF-funded Blue Waters petascale supercomputer at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign processes the stereo imagery into elevation models. The products, generated by a supercomputer, are distributed through arcticdem.org and are also available through Amazon Web Services.

The project also has involved other academic partners and Esri, a mapping company based in Redlands, Calif., that developed an online application, ArcticDEM Explorer, to analyze data.



Visible as a darker gray region in the center of this image made from ArcticDEM, the remote Siberian city of Yakutsk stretches between wilderness (green, yellow, and orange areas to the left) and the Lena River (blue) in northern Russia. Credit: Paul Morin, PGC

An Important Tool for Arctic Science and Modeling Hazards

Scientists and environmental managers say that ArcticDEM is an important tool for Arctic science and other applications. "It's a tremendous baseline of information for basic research related to land surface processes," said Scott Borg, acting deputy assistant director for geosciences at NSF.

Eric Rignot of the University of California, Irvine and NASA's Jet Propulsion Laboratory in Pasadena, Calif., told *Eos* that he will use ArcticDEM to process ice velocities of glaciers and ice sheets and said that it will also help clarify drainage boundaries between glaciers. It "will finally provide a useful reference in time from which we can measure changes in ice volume," he said.

The Asiaq Greenland Survey used ArcticDEM to make a detailed topographic map and a tsunami model after an 18 June 2017 landslide and tsunami at Karrat Fjord. One motivation was "to look for other areas in the same region that could fail in the same way," Morin said.

"Earth science is about change," he noted. "The surface is key to the past, and being able to measure changes in the surface is going to enable all different kinds of science, from coastal erosion and landslides, to forest management and civil engineering. Because we now have created a baseline for topography for about 10% of the land surface of the Earth, measurements in the future of topography can be measured against this data set."

By **Randy Showstack** (@RandyShowstack), Staff Writer

View the overall ArcticDEM on Eos.org http://bit.ly/ArcticDem

Geologic Map of Europa Highlights Targets for Future Exploration

Differentiating between a mountain range and a huge crack sometimes can be difficult, said planetary scientist Alex Patthoff. At least it's difficult when you're trying to identify features on a tiny moon nearly 600 million kilometers away.

This is just one of the obstacles Patthoff, a researcher at the Planetary Science Institute in Tucson, Ariz., and a team of scientists faced as they spent weeks poring over images of Jupiter's moon Europa to create the first global geological map of its surface. Patthoff and his colleague Erin Leonard first presented the research in October 2017 at the Geological Society of America's annual meeting in Seattle, Wash., and again at the 2017 AGU Fall Meeting in New Orleans, La.

Destination: Europa

At 3,100 kilometers in diameter, Europa is the smallest of the Galilean moons, which also include Callisto, Io, and Ganymede. It's one of the few moons in the solar system suspected of having a global ocean underneath an ice shell—a boon for scientists looking for life beyond Earth. Europa may even host geyser-like plumes similar to those on Saturn's moon Enceladus.

Europa's surface also seems relatively young: Although the other moons are pockmarked with craters, scientists see barely any on Europa's surface. This absence of craters could mean that its surface continuously forms anew, thus making Europa a geologically active world.

The Voyager spacecraft first revealed Europa's strange, red-streaked surface in 1979; the Galileo mission then discovered the internal ocean. Since then, scientists have wanted to return. NASA already has plans: In the 2020s, it intends to send an orbiter called Europa Clipper to the icy moon. And someday, it would really like to send a lander, but that dream is entirely hypothetical at this point.

But before we can send an orbiter or a lander, scientists need to know where to point the spacecraft to collect data, which means they need a map. Now they have one.

> "Most of the weirdness, for me at least, rises from the complexity of the surface."

Mapping Ice

To create the map, the researchers stitched together more than 100 images from the Voyager and Galileo missions to form a mosaic and then spent weeks identifying and categorizing surface features. These features include cracks, ridges, impact craters, regions called "chaos" where the icy surface seemed turbulently disrupted and uneven, and more.

Some problems arose—like trying to differentiate between a ridge and a crack, Patthoff said. Light sometimes plays tricks on the brain—a ridge can cast a shadow dark enough that it looks like a crack, for instance.

The finished map "really shows how the tectonics of the band structures and the chaos regions interact with each other at a global scale," said David Senske, the deputy project scientist for the Europa Clipper mission.

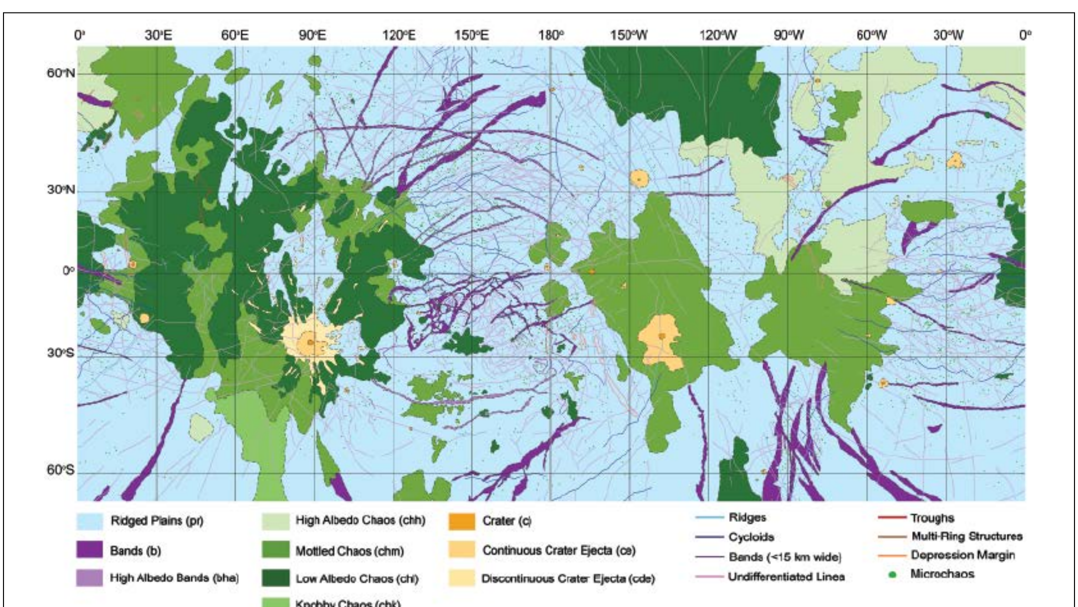
Global View

The global view allowed the mappers to start formulating more and more questions: Why are some features smooth lines and others jagged? What creates the chaos terrain? How does the internal ocean interact with the icy crust?

"Most of the weirdness, for me at least, rises from the complexity of the surface," said Leonard, who is a graduate student at University of California, Los Angeles and coauthor on the research. "I had only studied one region of Europa in depth, so the wide variety of features and the intense complexity of the surface were a bit shocking once I started looking at Europa's entire surface in detail."

One question Europa scientists hope to answer, among many, is, How thick is the moon's icy crust? A 20-kilometer-thick crust of ice could imply that convection occurs beneath the surface and no direct interaction takes place between the internal ocean and the surface. If the crust is just a few kilometers thick, however, the internal ocean could be interacting directly with the surface, creating the features spotted by Voyager and Galileo.

Now, armed with a shiny new map, scientists can target locations for future study to start answering their many questions.



Scientists created this map by stitching together more than 100 images of Europa's surface from the Voyager and Galileo spacecraft, then manually identifying key features. For polar projections, read the full article on Eos.org at http://bit.ly/EuropaGeoMap. Credit: NASA/Erin Leonard, Alex Patthoff, and Dave Senske, building on work by Ron Greeley, Thomas Doggett, and Melissa Bunte

By **JoAnna Wendel** (@JoAnnaScience), Staff Writer

Understanding a Changing West Antarctic Peninsula

The 1st Workshop of the SOOS WAP Working Group
Cambridge, United Kingdom, 15–16 May 2017

In Icy Waters: The Future of Marine Biogeochemical Research off the West Antarctic Peninsula
Chicheley, United Kingdom, 17–18 May 2017

The R/V Laurence M. Gould *casts its shadow on an iceberg along the West Antarctic Peninsula. This research vessel is deployed every January as part of the Palmer Long Term Ecological Research project to collect data and samples for a wide range of oceanographic studies. Credit: Grace Saba*

The West Antarctic Peninsula (WAP) has experienced some of Earth's most rapid winter warming in recent decades. This warming has been associated with significant declines in sea ice, changes in upper ocean physics, and altered food webs and biogeochemical cycles.

Two jointly coordinated meetings last year, involving more than 80 participants from 13 countries, addressed issues affecting this region. The Southern Ocean Observing System West Antarctic Peninsula (SOOS WAP; http://bit.ly/SOOS-WAP) Working Group meeting, held at the British Antarctic Survey headquarters, and the Royal Society meeting (see http://bit.ly/Royal-Soc-WAP) at the Kavli Royal Society International Centre brought together this large international community to examine the pronounced climatic changes—along with their biological and biogeochemical consequences—in this region. Within the context of rapid winter warming, the meetings also focused on defining the requirements for a WAP international ocean observing system to fill our knowledge gaps and address our future research priorities.

During the meetings, participants agreed on the overarching science drivers: the need to clearly define long-term WAP climate variability, along with associated ocean and atmosphere responses. Better understanding of key processes and interactions is important to determining to what degree climate variability and associated responses influence the significant ecosystem and ocean chemistry changes observed in this region.

Understanding connectivity among different components of the system is vital to understanding interactions between the atmosphere, ocean, and sea ice, as well as between organisms that live on the seafloor and those that live farther up in the water column. The participants agreed that the main barrier to this understanding was the lack of records spanning a term long enough to detect decadal variability.

Participants also discussed the effects of significant gaps in high-resolution spatial and temporal data. Filling these gaps could resolve the feedbacks between the ocean, atmosphere, ice, and land that drive the dynamics of this polar system, they noted. Notable was the lack of data for winter and early spring, before many of the national programs begin their sampling. Attendees agreed that the lack of data during this time of year is a particular challenge because new findings strongly suggest that these seasons are critical for physical changes in sea ice and ocean stratification and for the supply of nutrients. Both factors set strong controls on overall ecosystem productivity in the summer and associated biogeochemical cycling.

From discussions emerged a possible path forward: The harsh conditions during winter necessitate the integration of autonomous technologies capable of sustained operation on, in, and under the sea ice. Because the WAP data are highly patchy over a range of spatial scales, attendees agreed that such an integrated observing system would require improved regional ocean-atmosphere-ice models overlaid on a realistic bottom topography.

Another key finding that emerged during the meetings was that despite the presence of more than 30 international research stations (permanent or summer only) along the WAP, there are limited coordination and little standardization of scientific approaches among the national programs. Across the board, participants agreed that augmenting international collaboration, standardizing techniques, and opening up all data sources would be tremendous opportunities for science.

Acknowledgments
We thank SOOS, the Scientific Committee on Antarctic Research (SCAR), the Scientific Committee on Oceanic Research (SCOR), the Natural Environment Research Council (NERC), and the Royal Society (International Science Meeting grant IS160003).

By **Kate Hendry** (email: k.hendry@bristol.ac.uk), University of Bristol, Bristol, U.K.; **Sian Henley,** School of GeoSciences, University of Edinburgh, Edinburgh, U.K.; and **Oscar Schofield,** Rutgers University, New Brunswick, N.J.

Early-Career Scientists Discuss Paleoscience, Future Challenges

3rd PAGES Young Scientists Meeting
Morillo de Tou, Spain, 7–9 May 2017

Past Global Changes (PAGES), a core project of Future Earth, aims to improve past climate and environment reconstructions to better recognize their natural variability and, ultimately, inform strategies for sustainability. Paleoscientists who make up the PAGES community reconstruct components of the Earth system from a variety of natural and historical archives, and they integrate these data with models to better understand Earth's biosphere, cryosphere, atmosphere, and lithosphere.

The 3rd PAGES Young Scientists Meeting (YSM; http://www.pages-osm.org/ysm) brought together 80 early-career researchers (chosen from more than 200 applicants) from 23 countries in the small, restored ecovillage of Morillo de Tou in the Spanish Pyrenees. Twenty talks and 61 posters were presented in topical sessions that included abrupt change and threshold responses, biosphere and ecosystem dynamics, climate system dynamics, human-climate-ecosystem interactions, modeling, and new technical and methodological developments in paleoscience.

The scientific program also included keynote talks and three workshops on funding, communicating science, and data sharing. After the workshops, breakout groups discussed the increasing importance and challenges of improving communication skills, funding opportunities, future career paths, and priorities for paleoscience in the coming decade. These discussions highlighted the need for closer collaboration between proxy scientists and modelers to strengthen the integration between the two data sets, including the development of new approaches for data assimilation and proxy system models.

Participants discussed the possibility of establishing a PAGES early-career researchers group to promote young scientists' participation in the paleoclimate community and offer interdisciplinary networking opportunities. Delegates were encouraged to present thematic ideas for the new group, and they agreed that effective communication is essential to conveying the importance and relevance of paleoresearch. Accordingly, participants suggested that this group act as a platform for science outreach and education to broader, nonscientific audiences, particularly policy makers, local communities, and elementary schools.

YSM participants were warmly welcomed by the local communities, who have experienced profound effects related to climate change, intensive water management, and land use changes over the past century. The attention to climate change in this region was evident from the enthusiastic media coverage, which gave several participants unplanned opportunities to test their communication skills for an Aragon TV documentary on global climate change (see http://bit.ly/PAGES-video).

The local community entertained YSM participants with an evening of stargazing with members of the Huesca astronomical society and traditional dancing with a live band from the Aragon region.

Not only did the YSM facilitate the integration of the proxy and modeling research communities and provide a platform for interdisciplinary networking; it also helped participants to have the confidence to interact with well-established scientists at the 5th PAGES Open Science Meeting (OSM; http://www.pages-osm.org) in Zaragoza (attended by 900 people), which immediately followed the YSM.

The momentum from the YSM and the OSM has already led to the development of an informal online group. The group's purpose is to strengthen connections and develop future research collaboration opportunities among early-career researchers.

By **Vachel Carter** (email: kraklowv@natur.cuni.cz), Charles University, Prague, Czech Republic; **Liv Heinecke,** Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam, Germany; and **S. Yoshi Maezumi,** University of Exeter, Exeter, U.K.

A view of Mediano Reservoir located in Morillo de Tou, Spain, near the foothills of the Spanish Pyrenees. The dam was built in the 1940s for agricultural irrigation; the impoundment forced the original village to be relocated. The village was rebuilt in the 1980s, and this restored village was the location of the 3rd PAGES YSM. Credit: Angela Wade

To Understand Future Solar Activity, One Has to Know the Past

Staff Sgt. Erin O'Connell, a solar analyst with the U.S. Air Force 2nd Weather Squadron, creates a sunspot drawing from a projected image of the Sun at the Holloman Solar Observatory in New Mexico on 24 September 2015. Credit: Senior Airman Aaron Montoya, U.S. Air Force

Solar activity waxes and wanes in 10- to 11-year cycles; this is now general public knowledge. However, we know this only because of existing long-term records. Thanks to these histories, we also know that properties of solar cycles vary on timescales of 100 years and even longer. Thus, some of the most important processes on the Sun may take decades if not centuries to reveal themselves [*Owens*, 2013].

This long timescale means that some issues are not resolved, or even identified, at the time when data are acquired. Synoptic observations of solar activity, programs that span many years, feed future research to solve these issues.

However, present-day research funding schemes tend to focus on providing effective funding for rapidly changing research goals. Funding agencies and the U.S. National Academies emphasize short grants, lasting 3–5 years, as the prime vehicle for funding scientific research, a duration too short to ensure the survival of synoptic programs.

> Unfortunately, we are witnessing an alarming decline in funding, and even cancellation, of long-term programs.

How do we change this focus so that the synoptic studies so critical to our understanding get sustainable funding?

Insights Gained from Taking the Long View

Historical data show the presence of grand minima and grand maxima, when the Sun was either inactive or extremely active for an extended period. Those major changes in solar activity seem to have created significant changes in the past Earth climate, making long-term records essential to solving critical issues of the 21st century.

Even records of past solar activity that come from isotopic sources such as ice cores and tree rings rely on establishing a relationship between radiocarbon measurements and direct observations of solar activity. Because the natural circulation of carbon in Earth's atmosphere was affected by the explosive increase in the use of fossil fuels at the beginning of the Industrial Revolution, only historical observations of solar activity can be used for calibrating radiocarbon data. The absolute radiocarbon standard is based on wood from the year 1890.

Sometimes, historical records of direct observations of solar activity themselves may require critical analysis. Recently recalibrated records of sunspot numbers [*Clette et al.*, 2016] indicate, for instance, that solar cycle amplitudes may have been more uniform in the past 3 centuries than assumed until recently. If this result can be fully confirmed, it weakens the evidence for a solar cause of global warming.

We also have historical time series of direct measurements of sunspot magnetic field strengths and ultraviolet observations of the Sun going back more than a century. In combination with modern dynamo models, these historical data allow us to explore the possible changes in properties of solar plasma in the convection zone, where these magnetic fields are generated, and form a better understanding of future cycles. Paraphrasing Carl Sagan, "You have to know the past to understand the future."

Shortsighted Funding Strategies

Unfortunately, despite the importance of long-term time series, we are witnessing an alarming decline in funding, and even cancellation, of long-term programs. For example, 2016 brought us the disbanding of a solar group at Debrecen Heliophysical Observatory in Hungary, thus interrupting the recording of a historical time series of sunspot group areas that spans more than a century. (However, see

the comment at http://bit.ly/Debrecen-update for an update; the core scientific staff has continued its work.) This project had started at Greenwich Royal Observatory in May 1874 and was transferred to Debrecen at the end of 1978.

At Mount Wilson Observatory in California, scientists continue direct measurements of sunspot field strength that began in 1917. Funding for this project has been discontinued, but the effort lives on because of heroic efforts of remaining observing personnel. Similar cuts to sunspot measuring programs threaten research around the world.

Orchestrating Change

The success of long-term synoptic observations requires long-term sustainable funding. The short-duration project funding schemes that have prevailed in recent years are unsuitable for long-term data collection and continuous monitoring. Indeed, long-term continuity is a key requirement for producing meaningful and usable data sets.

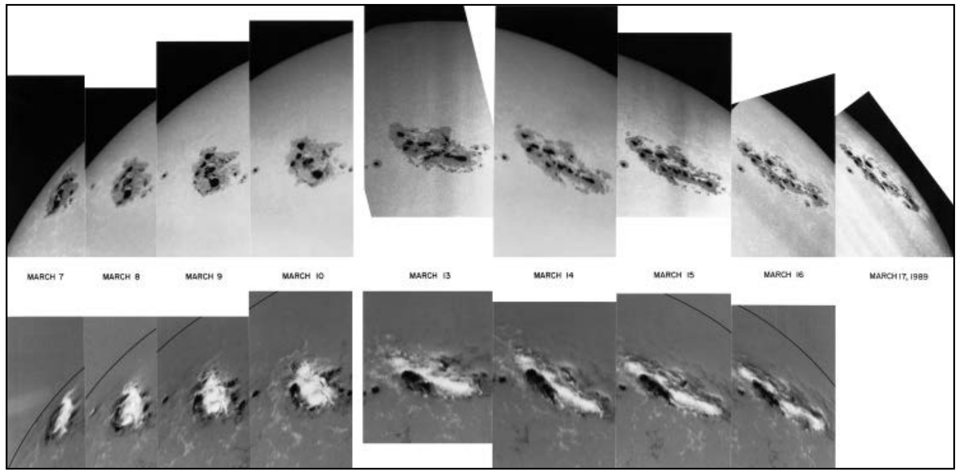
This does not mean that nothing changes over the term of a time series. Not all historical time series need to be continued, and instruments inevitably change over the lifetimes of long-term time series. However, change must be carefully planned and orchestrated to maintain the uniformity of a time series, including cross calibration of new and old instruments.

Although some efforts are being made to develop replacements for aging synoptic facilities, there is an overall lack of long-term planning for such programs. This lack of planning may lead to the creation of ad hoc "networks" of nonuniform instrumentation and unnecessary duplication.

This area of research also benefits from close international collaboration. One strategy for using funding efficiently would be to establish a list of observables that the international community considers worthy of continuing for an extended period of time. Then the funding agencies and the U.S. National Academies could be approached to establish a mechanism for shared funding for such time series. In this funding model, even countries with limited research capabilities may contribute to the overall success. To ensure the survival of historical time series, this work needs to be done *now*.

Our Obligation to Future Scientists

To some, conducting synoptic solar observations today may not seem as attractive as running space-based telescopes or the newest experimental instruments on the ground. Actually, our epoch proved highly efficient at exploiting past scientific records, thanks to modern computing and "big data" technologies, which often led to scientific breakthroughs.



A series of images of the Sun taken 7–17 March 1989 shows the evolution of a large sunspot group (NOAA 5395) as it moves around the Sun. The top sequence, taken in white light, shows the sunspot as it appears in the photosphere (solar visible surface). The bottom images are magnetograms of the same sunspot region, showing variations in magnetic polarity. During its disk passage, this active region produced more than 100 X-ray flares, including 11 flares in the most powerful X class. This eruptive activity was the cause of the "great geomagnetic storm" of 13–14 March, which affected radio communications and satellite operations and caused the famous Quebec blackout on 13 March 1989. See Allen et al. *[1989] for a detailed description of solar and geomagnetic activity associated with this active region. Credit: NOAO/AURA/NSF*

For example, one recent study [*Svalgaard*, 2016] used 46 million hourly measurements of the geomagnetic field to reconstruct the solar extreme ultraviolet flux from 1740 to 2015. If we neglect to continue these long-term data collection activities, we will prevent future generations of researchers from solving critical scientific issues that we can hardly foresee today.

Remember, the impacts of solar magnetic activity on our current technologies or global climate warming issues were completely unknown when Galileo, Schwabe, and Wolf began patiently recording dark sunspots centuries ago, but their efforts were vital to our current understanding of this impact. Scientists 15–20 years from now will perhaps wonder with disapproval why we did not continue the long-term record of observations.

Several recent meetings indicate a recognition of a growing demand in the solar physics community for sustainable and coordinated efforts in respect to long-term synoptic programs. One such meeting was the Splinter Meeting on Coordination of Synoptic Observations, held 16 October 2017 at the Max Planck Institute for Solar System Research in Göttingen, Germany (see http://bit.ly/SMCSO-2017). The U.S. National Academy of Sciences' Committee on Solar and Space Physics discussed long-term synoptic programs and data preservation at its 24–25 October 2017 meeting in Irvine, California (see http://bit.ly/CSSP-2017).

We live next to a variable star, and the only way to learn about its long-term behavior and, ultimately, to be able to predict it, is to guarantee the survival and continuity of long-term synoptic observations.

References

Allen, J., et al. (1989), Effects of the March 1989 solar activity, *Eos Trans. AGU, 70,* 1479, 1486–1488, https://doi.org/10.1029/89EO00409.

Clette, F., et al. (2016), Preface to topical issue: Recalibration of the sunspot number, *Sol. Phys., 91*(9), 2479–2486, https://doi.org/10.1007/s11207-016-1017-8.

Owens, B. (2013), Slow science: The world's longest-running experiments remind us that science is a marathon, not a sprint, *Nature, 495*(7441), 300–303, https://doi.org/10.1038/495300a.

Svalgaard, L. (2016), Reconstruction of solar extreme ultraviolet flux 1740–2015, *Sol. Phys., 291*(9), 2981–3010, https://doi.org/10.1007/s11207-016-0921-2.

By **Alexei A. Pevtsov** (email: apevtsov@nso.edu), National Solar Observatory, Boulder, Colo.; and **Frédéric Clette,** Solar Influences Data Analysis Center, Royal Observatory of Belgium, Brussels

Editor's Note: The authors are cochairs of the International Astronomical Union's Inter-Division B and E Working Group on Coordination of Synoptic Observations of the Sun (see http://bit.ly/IAU-Sun-WG). The National Solar Observatory is sponsored by the U.S. National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Taking the Pulse of the Planet

Fishermen ply their trade in the Gulf of Mannar in the Indian Ocean near Sri Lanka, one example of the vital importance of oceans to planet Earth and humankind. Measurements of ocean heating and sea level rise could prove more reliable than atmospheric measurements for tracking vital signs for the health of the planet. Credit: Jiang Zhu

Humans have released carbon dioxide and other greenhouse gases in sufficient quantities to change the composition of the atmosphere (Figure 1). The result is an accumulation of heat in Earth's system, commonly referred to as global warming. Earth's climate has responded to this influx of heat through higher temperatures in the atmosphere, land, and ocean. This warming, in turn, has melted ice, raised sea levels, and increased the frequency of extreme weather events, heat waves and heavy rains, for example. The results of these weather events include wildfires and flooding, among other things [*Intergovernmental Panel on Climate Change*, 2013].

Decision makers, scientists, and the general public are faced with critical questions: How fast is Earth's system accumulating heat, and how much will it warm in the future as human activities continue to emit greenhouse gases?

Here we explore better ways of measuring global warming to answer these questions. Natural temperature variability is much more muted in the ocean than in the atmosphere, owing to the ocean's greater ability to absorb heat (its heat capacity). As a result, ocean heating and sea level rise, which are measured independently, show stronger evidence that the planet is warming than does global average surface temperature, which relies on air temperature measurements. In other words, these ocean measurements could provide vital signs for the health of the planet.

Thus, we suggest that scientists and modelers who seek global warming signals should track how much heat the ocean is storing at any given time, termed global ocean heat content (OHC), as well as sea level rise (SLR). Similar to SLR, OHC has a very high signal-to-noise ratio; that is, it clearly shows the effects of climate change distinct from natural variability.

Why Do Changes in Surface Temperatures Obscure Signals from Global Warming?

To determine how fast Earth's systems are accumulating heat, scientists focus on Earth's energy imbalance (EEI): the difference between incoming solar radiation and outgoing longwave (thermal) radiation. Increases in EEI are directly attributable to human activities that increase carbon dioxide and other greenhouse gases in the atmosphere [e.g., *Trenberth et al.*, 2014].

The most visible sign of a warming climate is the increase in air temperature, which affects the climate and weather patterns. Changes in climate and weather affect the viability of plants and animals and our food and water supplies.

Monthly averages of global mean surface temperature (GMST) include natural variability, and they are influenced by the differing heat capacities of the oceans and landmasses.

Causes of natural variability include forcings that are external to the climate system (e.g., volcanic eruptions and aerosols and the 11-year sunspot cycle) and internal fluctuations (weather phenomena, monsoons, El Niño/La Niña, and decadal cycles).

All of these fluctuations make it difficult to extract the signal from noise in the measurements. But the oceans tell a different story.

Table 1. The Linear Trend (with 95% Confidence Level) for Three Key Climate Indicators: Global Mean Surface Temperature (GMST), Ocean Heat Content (OHC), and Sea Level Rise (SLR)[a]

	LINEAR TREND	σ	S/N (1/YEARS)	TIME (YEARS)
GMST	0.016°C ± 0.005°C/yr	0.110°C/yr	0.14	27
OHC	$0.79 \pm 0.03 \times 10^{22}$ J/yr	0.77×10^{22} J/yr	1.03	3.9
SLR	3.38 ± 0.10 mm/yr	3.90 mm/yr	0.87	4.6

[a]Also shown are the corresponding noise levels (standard deviation σ), signal-to-noise ratio (S/N), and the time in years required to detect a trend (approximately the time when the linear trend exceeds 4 times the interannual standard deviation). All values are for 2004–2015. Units: yr = year, J = joules, mm = millimeters.

What Global Warming Signals Can Be Found in the Oceans?

Scientists have long known that the extra heat trapped by increasing greenhouse gases mainly ends up in the oceans (more than 90%) [*Rhein et al.*, 2013]. Hence, to measure global warming, we have to measure ocean warming.

The oceans present myriad challenges for adequate monitoring. To take the ocean's temperature, it is necessary to use enough sensors at enough locations and at sufficient depths to track changes throughout the entire ocean. It is essential to have measurements that go back many years and that will continue into the future.

Since 2006, the Argo program of autonomous profiling floats has provided near-global coverage of the upper 2,000 meters of the ocean over all seasons [*Riser et al.*, 2016]. In addition, climate scientists have been able to quantify the ocean temperature changes back to 1960 on the basis of the much sparser historical instrument record [*Cheng et al.*, 2017].

From these temperature measurements, scientists extract OHC. These analyses show that during 2015 and 2016, the heat stored in the upper 2,000 meters of the world ocean reached a new 57-year record high (Figure 1). This heat storage amounts to an increase of 30.4×10^{22} joules since 1960 [*Cheng et al.*, 2017], equal to a heating rate of 0.33 watt per square meter averaged over Earth's entire surface: 0.61 watt per square meter after 1992. Improved measurements have revised these values upward by 13% compared with the results of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [*Rhein et al.*, 2013]. For comparison, the increase in OHC observed since 1992 in the upper 2,000 meters is about 2,000 times the total net generation of electricity by U.S. utility companies in the past decade [*U.S. Energy Information Administration,* 2016].

But what about heat capacity over the full ocean depth? The answer requires a bit more calculation. Any increase in heat contributes to the thermal expansion of seawater and, consequently, SLR [*Church et al.*, 2013]. Any energy added to Earth's system also causes land-based ice to melt, further contributing to SLR by adding water to the ocean.

Studies show that taking the full ocean depth, ice melt, and other factors into account, Earth is estimated to have gained 0.40 ± 0.09 watt per square meter since 1960 and 0.72 since 1992 [*Cheng et al.*, 2017], 18% higher than for the top 2,000-meter OHC alone.

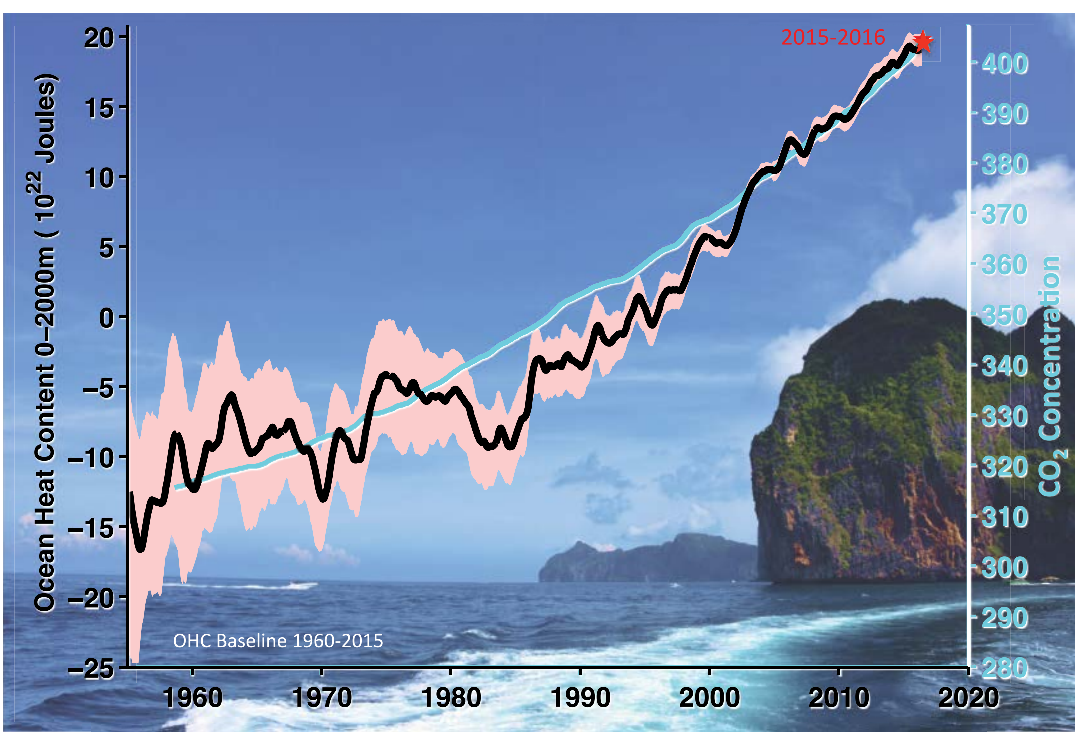


Fig. 1. Ocean heat content (OHC) and atmospheric carbon dioxide (CO_2) concentration measurements since 1958, shown as 12-month running means. The black curve represents ocean heating for the upper 2,000 meters of ocean, and light red shading represents the 95% confidence interval. CO_2 concentration observed at Mauna Loa Observatory is displayed by the light blue curve. Mean values for 2015–2016 are highlighted with a red star. The OHC is relative to a 1960–2015 baseline. Ocean heat data are from Cheng et al. *[2017], and CO_2 information is from the National Oceanic and Atmospheric Administration (see http://bit.ly/ESRL-greenhouse).*

Human-Caused Warming or Just Natural Variations?

The amplitude of the global warming signature (signal) compared with natural variability (noise) defines how well a metric tracks global warming. The "noise level," that is, the amplitude of internal variability, approximated here by the standard deviation (σ) of the OHC time series after the linear trend is removed, amounts to 0.77×10^{22} joules from 2004 to 2015 (Table 1). The linear trend of OHC is $0.79 \pm 0.03 \times 10^{22}$ joules per year within the same period (Figure 2).

So what time interval is needed to detect a trend given the noise within this time series? Working backward, the signal showing OHC increase, averaged over only 3.9 years, typically exceeds the noise at the 95% confidence level (outside ± 2σ error bars; Table 1). Thus, it is relatively straightforward to detect a long-term trend in OHC.

For the GMST record, the trend is 0.016°C ± 0.005°C per year for 2004–2015, and σ of the detrended GMST time series is 0.110°C (Table 1). These values and Figure 2 show that the noise is much larger than the signal. Thus, to detect a warming trend in the GMST record that exceeds a ±2σ noise level, scientists need at least 27 years of data.

Satellite altimetry has provided global observations of rising sea levels since the early 1990s [*Cazenave et al.*, 2014]. The linear trend of global mean SLR from 2004 to 2015 amounts to 3.38 ± 0.10 millimeters per year, and the σ of the detrended global mean is 3.90 millimeters (Table 1). Thus, 4.6 years is sufficient to detect a robust upward trend in SLR: a signal-to-noise ratio approximately 6 times larger than for GMST.

OHC and SLR Are Robust Indicators of Global Warming

A comparison of the changes and fluctuations in the three observational climate indicators (SLR, OHC, and GMST; Figure 2) clearly shows that both OHC and SLR are much better indicators of global warming than GMST is. These two measures are related but also sufficiently different and independently measured to be of interest.

The large fluctuations in GMST and its sensitivity to natural variability mean that using this measurement to argue that global warming is (or is not) happening requires care. An excellent example is the 1998–2013 period, during which energy was redistributed within Earth's system and the rise of GMST slowed [*Yan et al.,* 2016].

By contrast, the OHC and sea level increased steadily during this period, providing clear and convincing evidence that global warming continued.

The Need to Take the Pulse of the Planet

Monitoring past and current climate helps us better understand climate change and enables future climate projections. We must maintain and extend the existing global climate observing systems [*Riser et al.*, 2016; *von Schuckmann et al*., 2016] as well as develop improved coupled (ocean-atmosphere) climate assessment and prediction tools to ensure reliable and continuous monitoring for Earth's energy imbalance, ocean heat content, and sea level rise.

EEI has implications for the future and should be fundamental in guiding future energy policy and decisions; it is the heartbeat of the planet. Changes in OHC, the dominant measure of EEI, should be a fundamental metric along with SLR.

As we continue to scrutinize the fidelity of specific climate models, it is critical to validate their energetic imbalances as well as their depiction of GMST. The fact that the Coupled Model Intercomparison Project Phase 5 (CMIP5; http://bit.ly/CMIP5) ensemble mean accurately represents observed global OHC changes [*Cheng et al.*, 2016] is critical for establishing the reliability of climate models for long-term climate change projections.

Consequently, we recommend that both EEI and OHC be listed as output variables in CMIP6 models (see http://bit.ly/CMIP6-intro), in addition to SLR and GMST. This vital sign informs societal decisions about adaptation to and mitigation of climate change [*Trenberth et al.*, 2016].

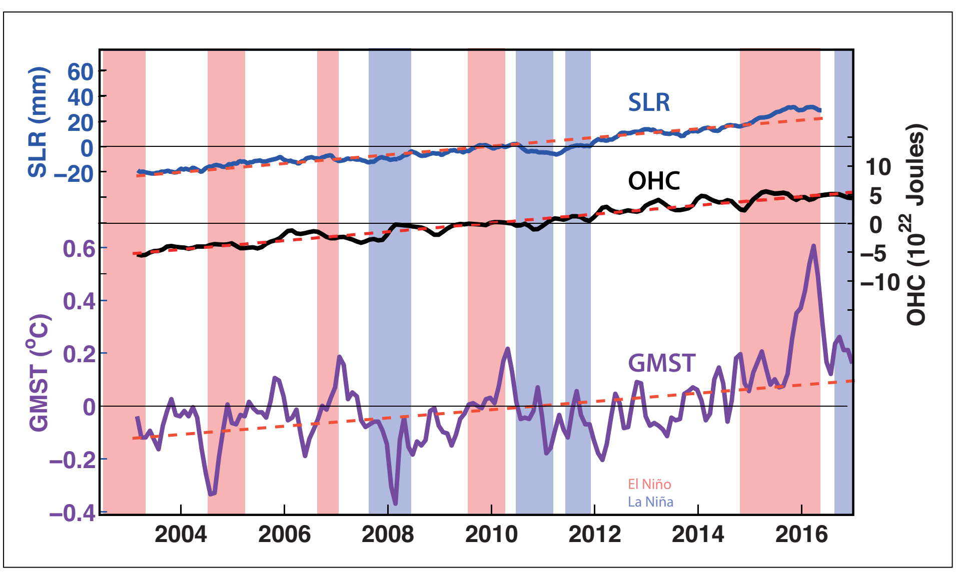


Fig. 2. Changes in OHC, global mean surface temperature (GMST), and sea level rise (SLR) during the past decade. All values are 2-month means; the dashed red lines indicate linear trends. The scale of the y axis is adjusted so that the linear trend has exactly the same slope for all three indices. El Niño events are marked as pale red bars, and the La Niña events are pale blue bars. All time series are referenced to a 2004–2015 mean. The OHC (http://bit.ly/OHC-by-IAP), GMST (https://go.nasa.gov/2hr1xlA), and sea level (http://sealevel.colorado.edu) data reported are archived.

Acknowledgments

L.C. and J.Z. were supported by XDA11010405. K.E.T. and J.F. were partially sponsored by the U.S. DOE (DE-SC0012711). The National Center for Atmospheric Research (NCAR) is sponsored by the U.S. National Science Foundation.

References

Cazenave, A., et al. (2014), The rate of sea-level rise, *Nat. Clim. Change, 4*(5), 358–361, https://doi.org/10.1038/nclimate2159.

Cheng, L., et al. (2016), Observed and simulated full-depth ocean heat content changes for 1970–2005, *Ocean Sci., 12,* 925–935, https://doi.org/10.5194/os-12-925-2016.

Cheng, L., et al. (2017), Improved estimates of ocean heat content from 1960 to 2015, *Sci. Adv., 3,* e1601545, https://doi.org/10.1126/sciadv.1601545.

Church, J. A., et al. (2013), Sea level change, in *Climate Change 2013: The Physical Science Basis,* edited by T. F. Stocker et al., Cambridge Univ. Press, Cambridge, U.K., https://doi.org/10.1017/CBO9781107415324.026.

Intergovernmental Panel on Climate Change (2013), *Climate Change 2013: The Physical Science Basis,* edited by T. F. Stocker et al., Cambridge Univ. Press, Cambridge, U.K., https://doi.org/10.1017/CBO9781107415324.

Rhein, M., et al. (2013), Observations: Ocean, in *Climate Change 2013: The Physical Science Basis,* edited by T. F. Stocker et al., Cambridge Univ. Press, Cambridge, U.K., https://doi.org/10.1017/CBO9781107415324.010.

Riser, S. C., et al. (2016), Fifteen years of ocean observations with the global Argo array, *Nat. Clim. Change, 6,* 145–153, https://doi.org/10.1038/nclimate2872.

Trenberth, K., J. Fasullo, and M. Balmaseda (2014), Earth's energy imbalance, *J. Clim., 27,* 3129–3144, http://dx.doi.org/10.1175/JCLI-D-13-00294.1.

Trenberth, K. E., M. Marquis, and S. Zebiak (2016), The vital need for a climate information system, *Nat. Clim. Change, 6,* 1057–1059, https://doi.org/10.1038/nclimate3170.

U.S. Energy Information Administration (2016), Electric power annual 2015, U.S. Dep. of Energy, Washington, D. C., https://www.eia.gov/electricity/annual/html/epa_01_02.html.

von Schuckmann, K., et al. (2016), An imperative to monitor Earth's energy imbalance, *Nat. Clim. Change, 6,* 138–144, https://doi.org/10.1038/nclimate2876.

Yan, X.-H., et al. (2016), The global warming hiatus: Slowdown or redistribution?, *Earth's Future, 4,* 472–482, https://doi.org/10.1002/2016EF000417.

By **Lijing Cheng** (@Lijing_Cheng), International Center for Climate and Environment Sciences, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China; **Kevin E. Trenberth** (email: trenbert@ucar.edu) and **John Fasullo** (@jfasullo), National Center for Atmospheric Research, Boulder, Colo.; **John Abraham,** University of St. Thomas, St. Paul, Minn.; **Tim P. Boyer,** National Centers for Environmental Information, National Oceanic and Atmospheric Administration, Silver Spring, Md.; **Karina von Schuckmann,** Mercator Océan, Ramonville-Saint-Agne, France; and **Jiang Zhu,** International Center for Climate and Environment Sciences, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

AGU100

ADVANCING EARTH AND SPACE SCIENCE

AGU: Founded in 1919

centennial.agu.org

#AGU100

How Will Climate Change Affect the United States in Decades to Come?

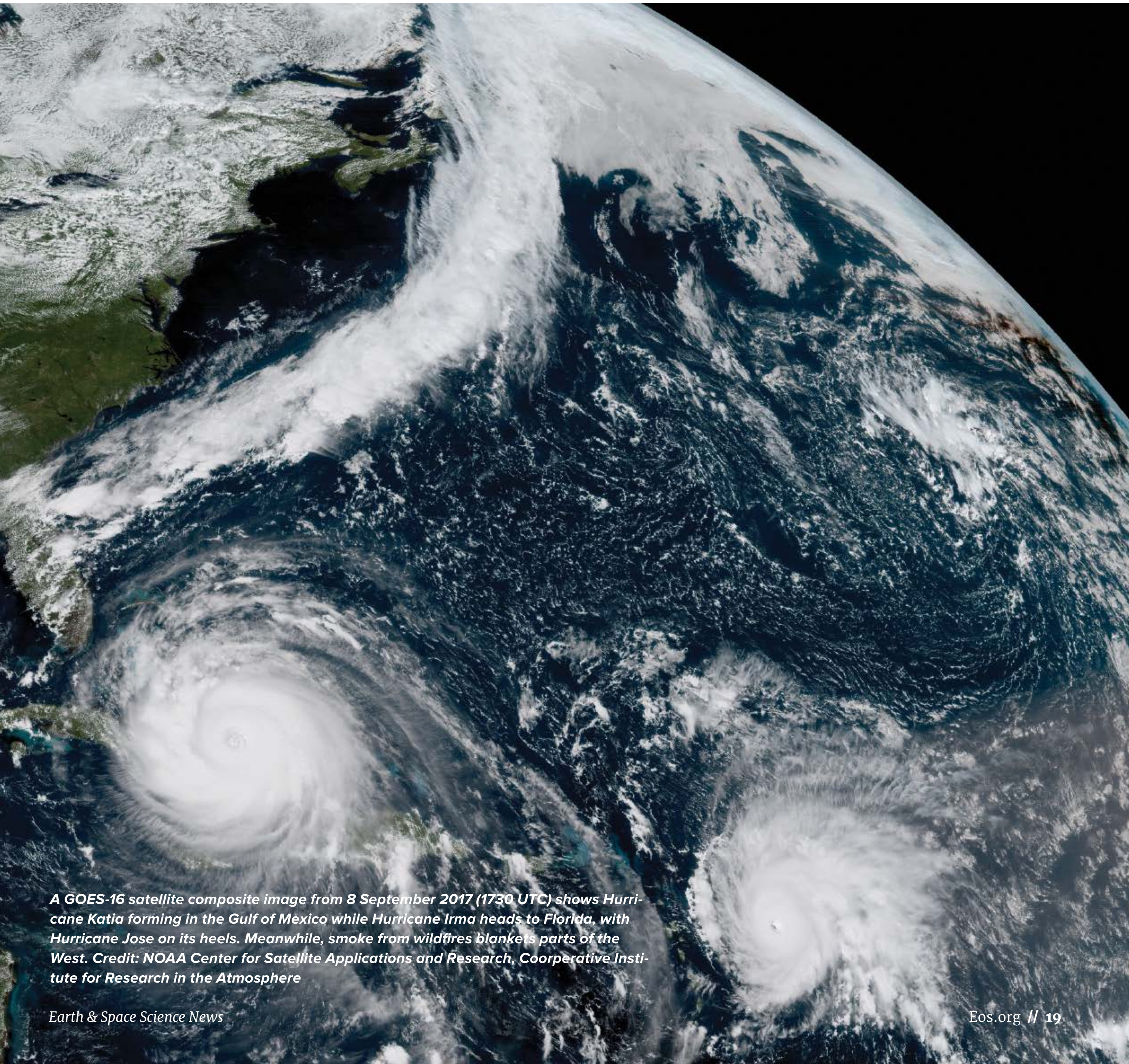
A new U.S. government report shows that climate is changing and that human activities will lead to many more changes. These changes will affect sea levels, hurricane frequency, wildfires, and more.

By Donald Wuebbles, David W. Fahey, and Kathy A. Hibbard

Scientists released a report on 3 November that details how climate change is affecting weather and climate across the United States and how future changes in climate could play out across the country.

The Climate Science Special Report (CSSR), created by a U.S. government organization that coordinates and integrates federal research on changes in the global environment and their implications for society, also lays out the current state of science relating to climate change and its physical effects (see httpst://science2017.globalchange.gov/).

"It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century," the report



A GOES-16 satellite composite image from 8 September 2017 (1730 UTC) shows Hurricane Katia forming in the Gulf of Mexico while Hurricane Irma heads to Florida, with Hurricane Jose on its heels. Meanwhile, smoke from wildfires blankets parts of the West. Credit: NOAA Center for Satellite Applications and Research, Coorperative Institute for Research in the Atmosphere

concludes. “For the warming over the last century, there is no convincing alternative explanation supported by the extent of the observational evidence.”

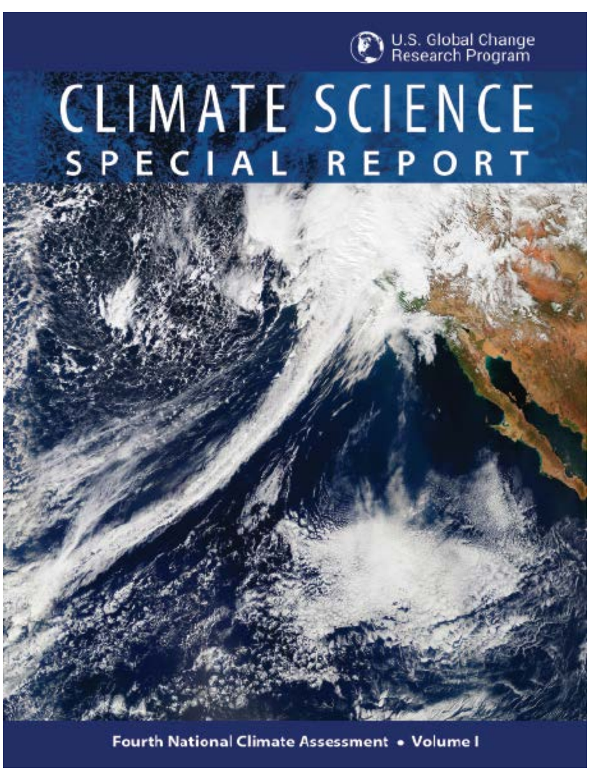
And the observational evidence is manifold. Thousands of studies outlined in the report document rising surface, atmospheric, and oceanic temperatures; melting glaciers; diminishing snow cover; shrinking sea ice; rising sea levels; ocean acidification; and increasing intensity and frequency of rainfall, hurricanes, heat waves, wildfires, and drought. The report meticulously outlines how these effects can be traced largely back to human activities and associated emissions of radiatively important gases and particles.

Underlying the report is a broad scientific consensus: The farther and the faster the Earth system is pushed toward more change, the greater the risk is of unanticipated effects, some of which are potentially large and irreversible.

For example, without major reductions in emissions, the increase in annual average global temperature relative to preindustrial times could reach 9°F (5°C) or more by the end of this century. Although emission rates have slowed as economic growth is becoming less carbon intensive, this slowing trend is not yet at a rate that would limit global average temperature change to 3.6°F (2°C) above preindustrial levels by century’s end.

And there’s more. Sea levels are likely to continue to rise, and many severe weather events are likely to become more intense. Brace for more record-breaking high temperatures, including multiday heat waves, and more severe precipitation when it rains or snows. Drought could plague the western United States for decades to come. Atlantic and Pacific hurricanes are expected to get even more intense.

In other words, the report shows that our current emissions trajectories will bring our planet into a very different climate state than it is in today, with profound effects for the United States.



The cover of a newly released U.S. government report on climate science. Credit: Jesse Allen, NASA Earth Observatory/VIIRS/Suomi-NPP

An Authoritative Voice on the United States’ Climate Future

The CSSR was created by the U.S. Global Change Research Program (USGCRP) as volume 1 of the Fourth National Climate Assessment (NCA4) [*Wuebbles et al.*, 2017]. USGCRP oversaw the production of this stand-alone report of the state of science relating to climate change and its physical impacts. CSSR is designed to be an authoritative assessment of the science of climate change, with a focus on the United States, to serve as the foundation for efforts to assess climate-related risks and inform decision-making about responses.

The CSSR serves several purposes, including providing (1) an updated and detailed analysis of the findings of how climate change is affecting weather and climate across the United States, (2) an executive summary and 15 chapters that provide the basis for the discussion of climate science, and (3) foundational information and projections for climate change, including extremes, to improve “end-to-end” consistency in sectoral, regional, and resilience analyses.

The CSSR integrates and evaluates the findings on climate science and discusses the uncertainties associated with these findings. It analyzes current trends in climate change, human induced and natural, and projects major trends to the end of this century.

The National Oceanic and Atmospheric Administration (NOAA) is the lead administrative agency for the current report. Other agencies involved include NASA and the Department of Energy; representatives from national laboratories, universities, and the private sector also helped write the report.

The report underwent several drafts and multiple reviews, including one by the public, and expert reviews by the 13 USGCRP agencies and the National Academies of Sciences, Engineering, and Medicine. What results is a comprehensive document on the state of climate science, with assessments of statistically likely scenarios of climate in the United States through the end of the century.

Advances in Science Since the Last Assessment

The CSSR represents the most comprehensive assessment of the science done for an NCA. As such, the report

See page 4 for a news item about the White House release of this climate science report.

reflects a number of advances in climate science since the Third U.S. National Climate Assessment (NCA3) was published, in 2014.

For example, since NCA3, stronger evidence has emerged for the ongoing, rapid, human-caused warming of the global atmosphere and ocean. Researchers can now more closely pinpoint the human influences for individual extreme climate and weather events.

In addition, significant advances have been made in understanding extreme weather events in the United States and how they relate to increasing global temperatures and associated climate changes. The new report also discusses the extent to which atmospheric circulation in the midlatitudes is changing or is projected to change, possibly in ways not captured by current climate models.

For the first time in the NCA process, sea level rise projections incorporate geographic variation based on factors such as local land subsidence, ocean currents, and changes in Earth's gravitational field. In an examination of potential risks, the CSSR found that both large-scale state shifts in the climate system (sometimes called tipping points) and compound extremes have the potential to generate unanticipated climate surprises.

Report Highlights: Global Perspective

At the heart of the report are some indisputable facts. The global atmospheric carbon dioxide (CO_2) concentration is now everywhere more than 400 parts per million (ppm), a level that last occurred about 3 million years ago, when both global average temperature and sea level were significantly higher than today. Continued growth in human-made emissions of CO_2 over this century and beyond would lead to an atmospheric concentration not experienced in tens to hundreds of millions of years.

What's more, the past 115 years are now the warmest such time span in at least the last 1,700 years. Global annually averaged surface air temperature has increased by about 1.8°F (1.0°C) since 1901 (Figure 1).

Many other aspects of global climate are changing. For example, global average sea level has risen by about 7–8 inches since 1900, with almost half (about 3 inches) of that rise occurring since 1993. Human-caused climate change has made a substantial contribution to this rise, contributing to a rate of rise that is greater than during any preceding century in at least 2,800 years.

Global average sea levels are expected to continue to rise, by at least several inches in the next 15 years and by 1–4 feet by 2100. A rise of as much as 8 feet by 2100 cannot be ruled out.

What Does This Mean for the United States?

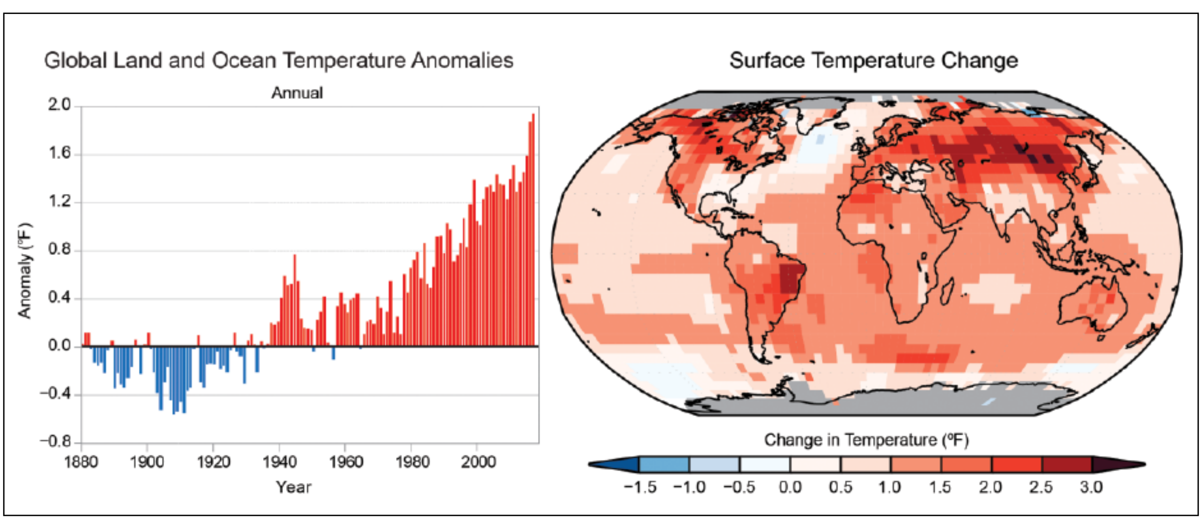
Annual average temperature over the contiguous United States has increased by 1.8°F (1.0°C) over the period from 1901 to 2016; over the next few decades (2021–2050), annual average temperatures are expected to rise by about 2.5°F for the United States, relative to the recent past (average from 1976–2005), under all plausible future climate scenarios.

The report documents how, across the board, the higher temperatures projected for the United States and the world are expected to increase the intensity and frequency of extreme events. Changes in the characteristics of extreme events are particularly important for human safety, infrastructure, agriculture, water quality and quantity, and natural ecosystems.

Below are peeks into some of the realms in which the United States is expected to face profound change. What's striking here is that events that we consider to be extreme may become the new normal by century's end.

Coastal flooding. Global sea level rise has already affected the United States; the incidence of daily tidal flooding is accelerating in more than 25 Atlantic and Gulf Coast cities. Sea level rise is expected to be higher than the global average in some parts of the United States, especially on the East and Gulf coasts. This is due, in part, to changes in Earth's gravitational field from melt-

Fig. 1. (left) Global annual average temperature has increased by more than 1.2°F (0.7°C) for the period 1986–2016 relative to 1901–1960. Red bars show temperatures that were above the 1901–1960 average, and blue bars indicate temperatures below the average. (right) Surface temperature change (in °F) for the period 1986–2016 relative to 1901–1960. Gray indicates missing data. Credit: CSSR, chapter 1, USGCRP



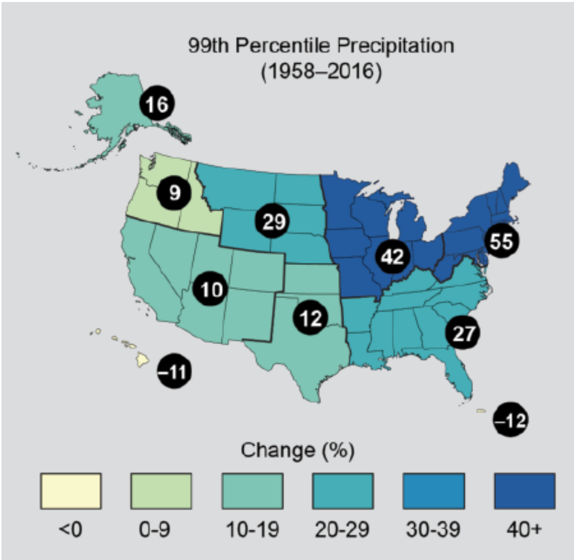


Fig. 2. Percentage changes in the amount of precipitation falling in very heavy events (the heaviest 1%) from 1958 to 2016 for the United States on a regional basis. There is a clear national trend toward a greater amount of precipitation being concentrated in very heavy events, particularly in the Northeast and Midwest. Credit: Updated from NCA3; CSSR, chapter 7, USGCRP

ing land ice, changes in ocean circulation, and local subsidence.

Larger precipitation events. Heavy precipitation, as either rainfall or snowfall, is increasing in intensity and frequency across the United States (Figure 2) and the globe. These trends are expected to continue. The largest observed changes in extreme precipitation in the United States have occurred in the Northeast and the Midwest.

Heat waves. Heat waves have become more frequent in the United States since the 1960s, whereas extreme cold temperatures and cold waves have become less frequent. Recent record-setting warm years are projected to become common in the near future for the United States as annual average temperatures continue to rise.

Forest fires. The incidence of large forest fires in the western contiguous United States and Alaska has increased since the early 1980s and is projected to further increase in those regions as the climate warms, with profound changes to regional ecosystems. The frequency of large wildfires is influenced by a complex combination of natural and human factors.

Drought. Annual trends toward earlier spring snowmelt and reduced snowpack are already affecting water resources in the western United States, with adverse effects for fisheries and electricity generation. These trends are expected to continue. Under the highest emissions scenarios (representative concentration pathway (RCP) 8.5) and assuming no change in current water resources management, chronic, long-duration hydrological drought is increasingly possible before the end of this century.

Recent droughts and associated heat waves have reached record intensity in some U.S. regions. The report notes that evaluating the human effect on recent major U.S. droughts is complicated at this time. Little evidence is found for a human influence on observed precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures.

Hurricanes. Physical processes suggest, and numerical modeling simulations generally confirm, an increase in tropical cyclone intensity in a warmer world, and Earth system models generally show an increase in the number of very intense tropical cyclones. For Atlantic and eastern North Pacific hurricanes, increases are projected in precipitation rates and intensity. The frequency of the most intense of these storms is projected to increase in the Atlantic and western North Pacific and in the eastern North Pacific.

Atmospheric rivers. These narrow streams of moisture account for 30%–40% of the typical snowpack and annual precipitation on the U.S. West Coast. They are also associated with severe flooding events when they shed their moisture. The frequency and severity of land-falling atmospheric rivers will increase because rising temperatures increase evaporation, resulting in higher atmospheric water vapor concentrations.

A Fate Dependent on Emissions

The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse gases (especially carbon dioxide) emitted globally. And without significant cuts to emissions, annual average global temperatures will almost certainly rise beyond 2°C by the end of the century.

In other words, the oft-stated goal of keeping globally averaged temperature change at or below this level to minimize potential impacts on humans and ecosystems can be met only through substantial reductions in emissions before 2040. Choices made today will determine the magnitude of climate change risks beyond the next few decades.

With significant reductions in emissions, the increase in annual average global temperature could be limited to 3.6°F (2°C) or less. Figure 3 shows the projected changes in U.S. temperature for two possible future pathways.

The science is in, and the CSSR documents it in a way that's both comprehensive and revelatory. It also provides important input to the development of other parts of NCA4, which will focus primarily on the human welfare, societal, economic, and environmental elements of climate change. Volume 2 of NCA4, with an emphasis on the impacts of climate change, is planned for publication in late 2018.

Acknowledgments

Writing the CSSR required the concerted effort of a large, diverse, and experienced author team of climate scientists from across the United States working for many months. The USGCRP provided organization and guidance for the overall process, NOAA provided oversight as the lead agency, and NOAA National Centers for Envi-

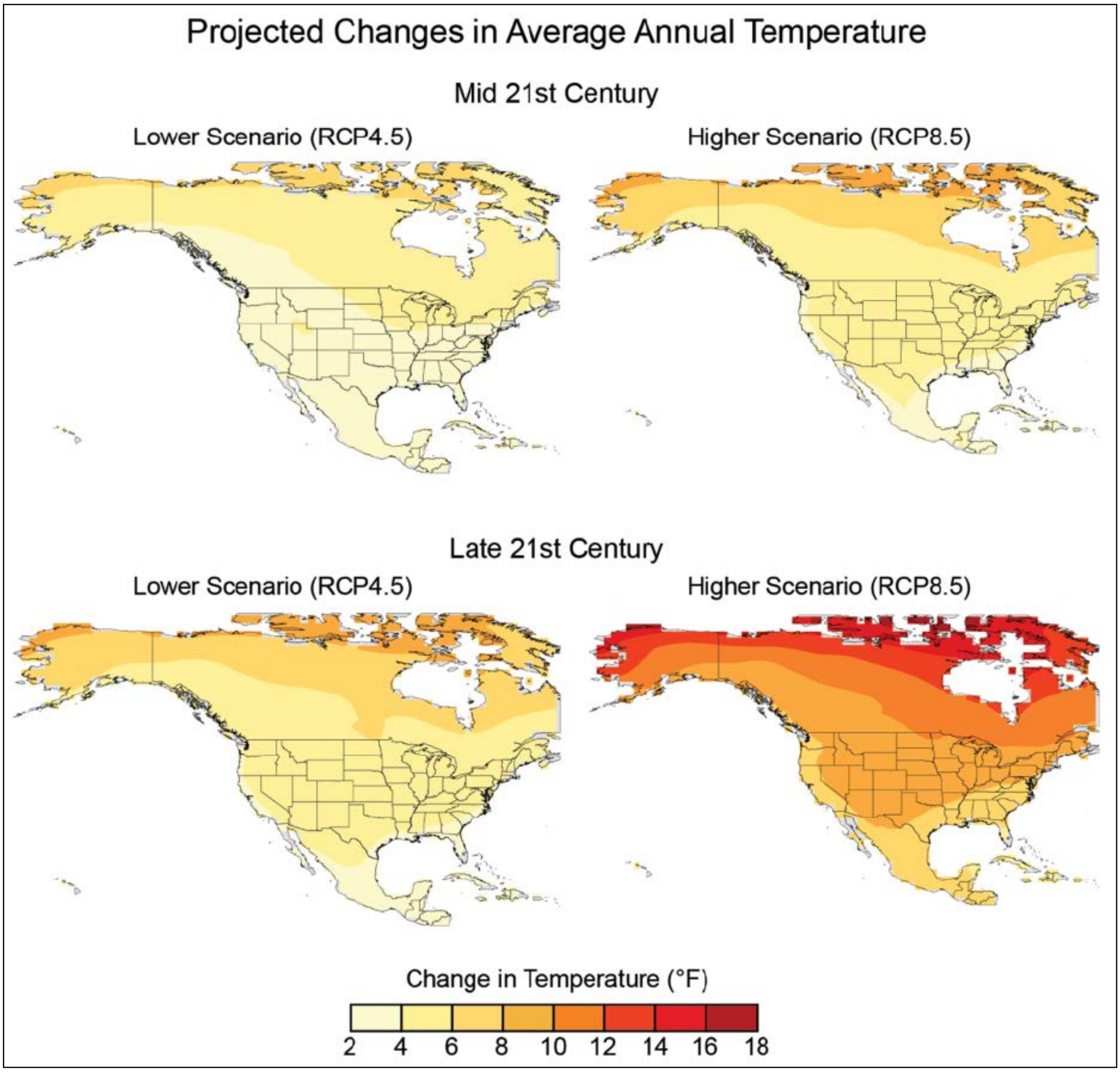


Fig. 3. Projected changes in average annual temperatures (°F) for North America under two representative concentration pathways (RCPs) identified in the Intergovernmental Panel on Climate Change's Fifth Assessment Report. RPCs are greenhouse gas concentration trajectories, so named because they represent the change in radiative forcing values (e.g., +4.5 watts per square meter) modeled for 2100 relative to preindustrial times. Shown here is the difference between the average temperatures for (top) midcentury (2036–2065) and (bottom) late century (2071–2100) and the average temperatures for near present (1976–2005). Each map depicts the weighted multimodel mean. Increases are statistically significant in all areas (i.e., more than 50% of the models show a statistically significant change, and more than 67% agree on the sign of the change). Analyses are based on downscaled analyses of the Coupled Model Intercomparison Project 5 models. Credit: CSSR, chapter 6, LOCA CMIP6

ronmental Information provided technical, editorial, and production support for the document drafts and final product. We appreciate the independent reviews from the public and that conducted by the National Academy of Sciences.

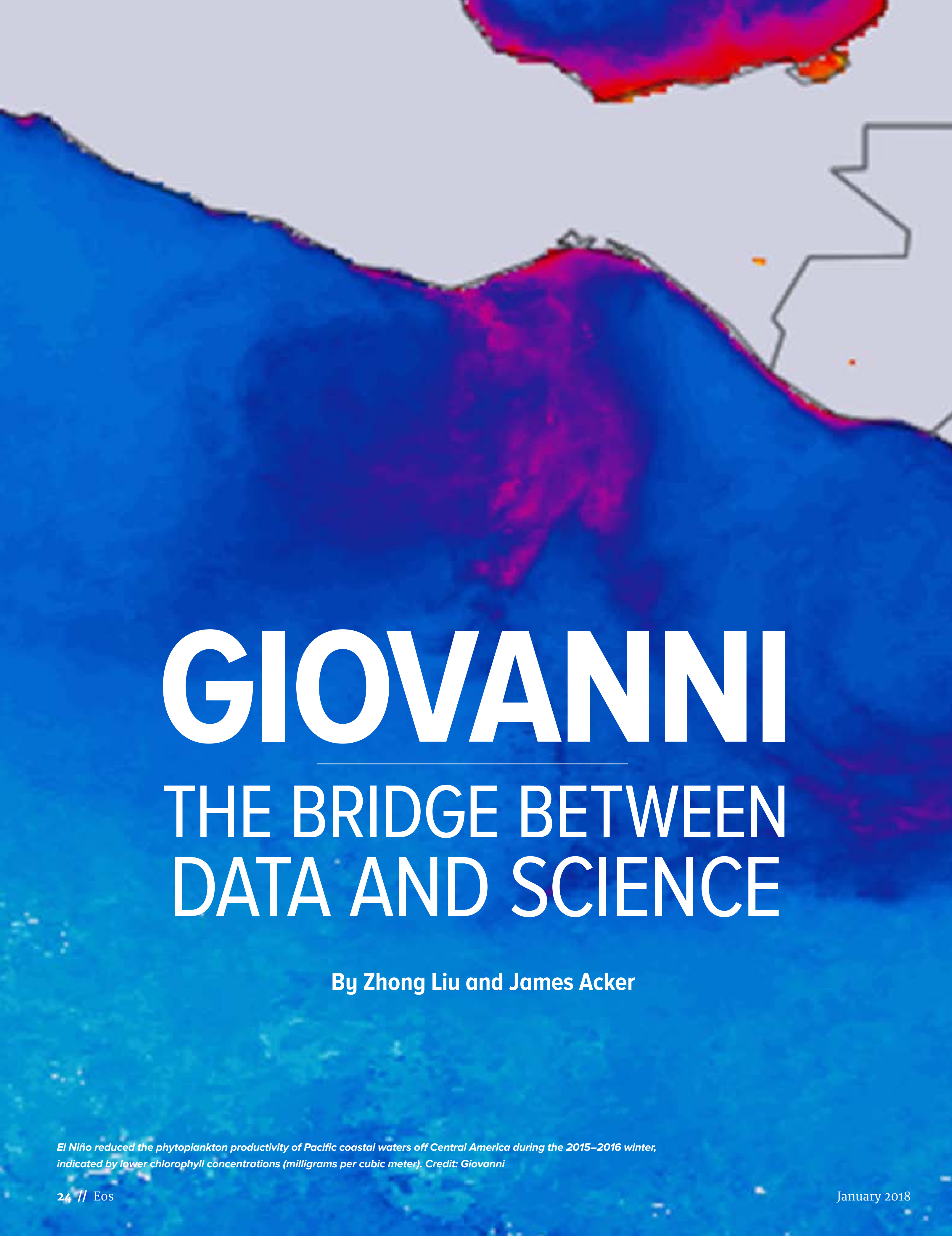
References

Wuebbles, D. J., et al. (Eds.) (2017), *Climate Science Special Report: Fourth National Climate Assessment,* vol. 1, U.S. Global Change Res. Program, Washington, D. C.

Author Information

Donald Wuebbles (email: wuebbles@illinois.edu), Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, Urbana; **David W. Fahey,** Earth System Research Laboratory, National Oceanic and Atmospheric Administration, Boulder, Colo.; and **Kathy A. Hibbard,** Earth Science Division, NASA Headquarters, Washington, D. C.

Editor's Note: The authors of this Eos *feature are the lead authors of the Climate Science Special Report. Donald Wuebbles was employed at the White House Office of Science and Technology Policy in Washington, D. C., and the National Science Foundation in Arlington, Va., while the report was being prepared.*

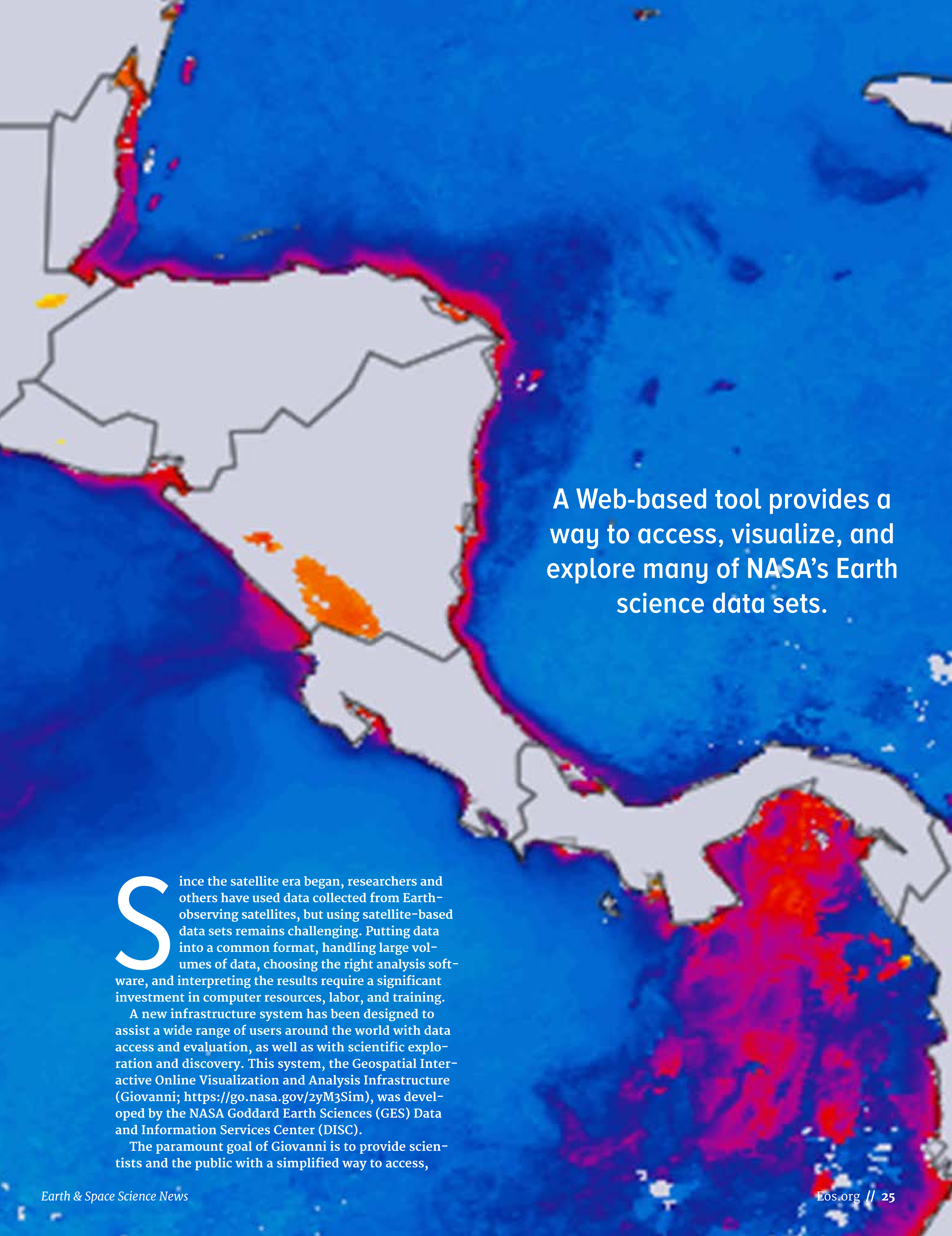


GIOVANNI

THE BRIDGE BETWEEN DATA AND SCIENCE

By Zhong Liu and James Acker

El Niño reduced the phytoplankton productivity of Pacific coastal waters off Central America during the 2015–2016 winter, indicated by lower chlorophyll concentrations (milligrams per cubic meter). Credit: Giovanni



A Web-based tool provides a way to access, visualize, and explore many of NASA's Earth science data sets.

Since the satellite era began, researchers and others have used data collected from Earth-observing satellites, but using satellite-based data sets remains challenging. Putting data into a common format, handling large volumes of data, choosing the right analysis software, and interpreting the results require a significant investment in computer resources, labor, and training.

A new infrastructure system has been designed to assist a wide range of users around the world with data access and evaluation, as well as with scientific exploration and discovery. This system, the Geospatial Interactive Online Visualization and Analysis Infrastructure (Giovanni; https://go.nasa.gov/2yM3Sim), was developed by the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC).

The paramount goal of Giovanni is to provide scientists and the public with a simplified way to access,

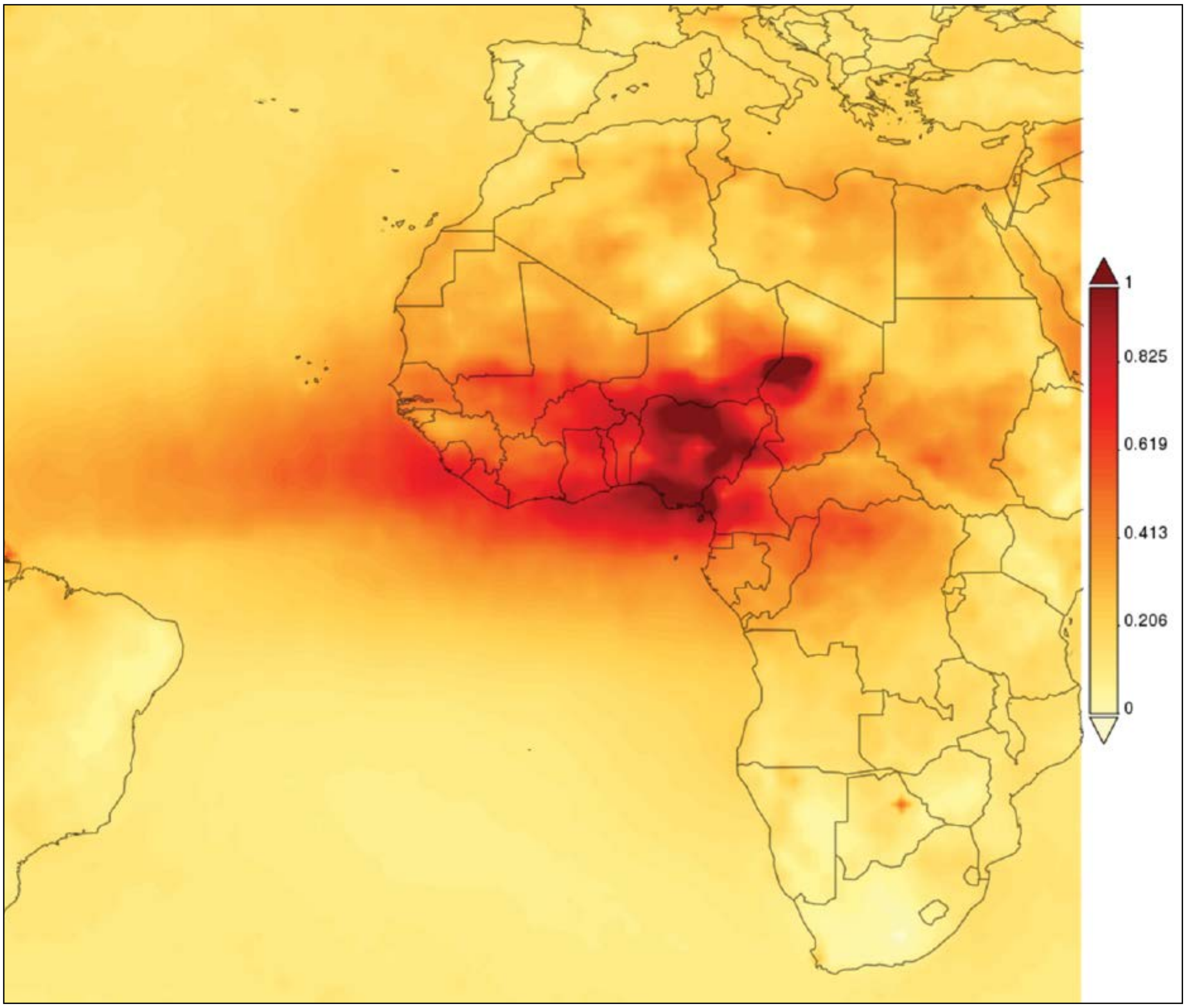


Fig. 1. This time-averaged satellite map of the March aerosol optical thickness off the coast of western Africa from 2003 to 2016 incorporates several of the new capabilities of NASA's Giovanni data visualization infrastructure. Credit: Giovanni

evaluate, and explore NASA satellite data sets. Here we describe the latest capabilities of Giovanni with examples (like the optical thickness map in Figure 1), and we discuss potential future plans for this innovative system.

Challenges of Using Satellite Data

Over Earth's vast oceans and remote continents, traditional large-scale, ground-based programs to observe the atmosphere, ocean, and land surface can be difficult and costly to deploy and maintain and are therefore impractical for providing adequate long-term observational data for research and applications. However, the need for large-scale observations is increasing as global observations become substantially more important for understanding global change processes like temperature and precipitation shifts.

Satellite instruments can overcome surface observation limitations by making repeated, synoptic observations of the Earth's land surface, ocean, and atmosphere. For example, NASA's Earth Observing System (EOS) is a global observation campaign consisting of a coordinated series of polar-orbiting satellites intended for long-term global observations, enabling improved understanding of Earth's geophysical systems.

However, many researchers find it challenging to access and use NASA data. Heterogeneous data formats, complex data structures, large-volume data storage, special programming requirements, diverse analytical software options, and other factors require a significant investment in time and resources, especially for novices.

By facilitating data access and evaluation, as well as promoting open access to create a level playing field for nonfunded scientists, NASA data can be more readily used for scientific discovery and societal benefits. Giovanni was developed to advance this goal. With Giovanni's assistance, researchers around the world have published more than 1,300 peer-reviewed papers in a wide range of Earth science disciplines and other areas.

A Brief History of Giovanni

Giovanni was initiated and developed for faster and easier access to and evaluation of data sets at GES DISC [*Liu*

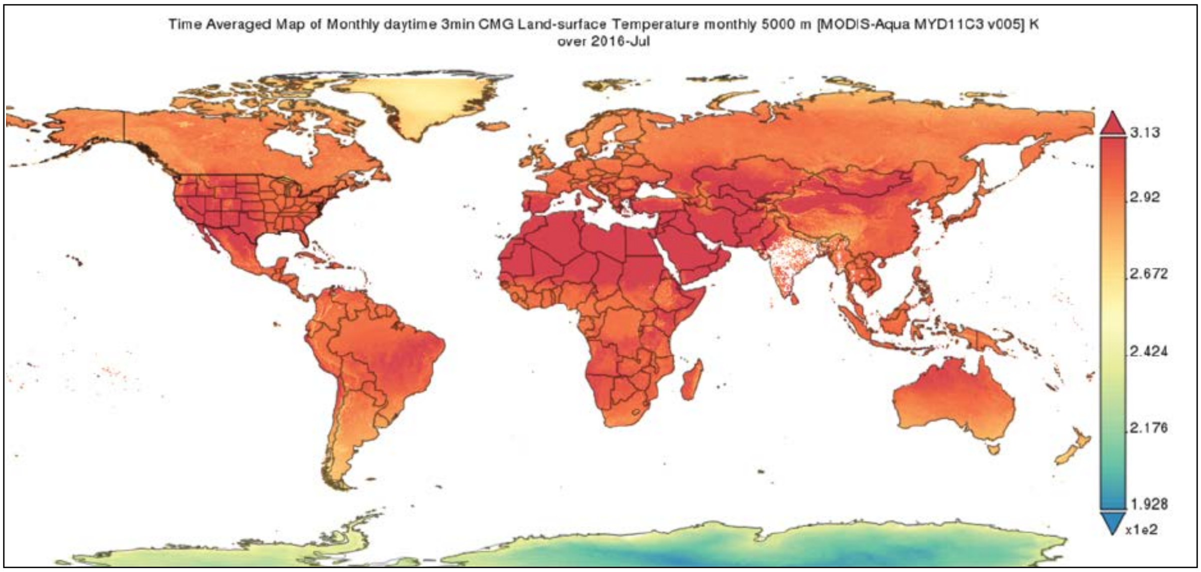


Fig. 2. July 2016, the hottest month on record for the globe. Shown are Moderate Resolution Imaging Spectroradiometer (MODIS) day surface temperatures (in kelvins). Credit: Giovanni

et al., 2007; *Acker and Leptoukh,* 2007; *Berrick et al.,* 2009]. The first implementation of Giovanni was an online visualization and analysis system for tropical rainfall data sets from NASA's Tropical Rainfall Measuring Mission (TRMM).

As the project gained popularity, scientists requested that more satellite data sets be included in Giovanni. To address this demand, we created multiple discipline- or mission-based data portals. The current Giovanni has evolved further, featuring a new unified Web interface to support interdisciplinary Earth system research, allowing synergistic use of data sets from different satellite missions.

A Wide Selection of Data Sets

Giovanni provides access to numerous satellite data sets, concentrated primarily in the areas of atmospheric composition, atmospheric dynamics, global precipitation, hydrology, and solar irradiance.

More than 1,600 variables are currently available in Giovanni. The Web interface has keyword and faceted search capabilities for locating variables of interest. For

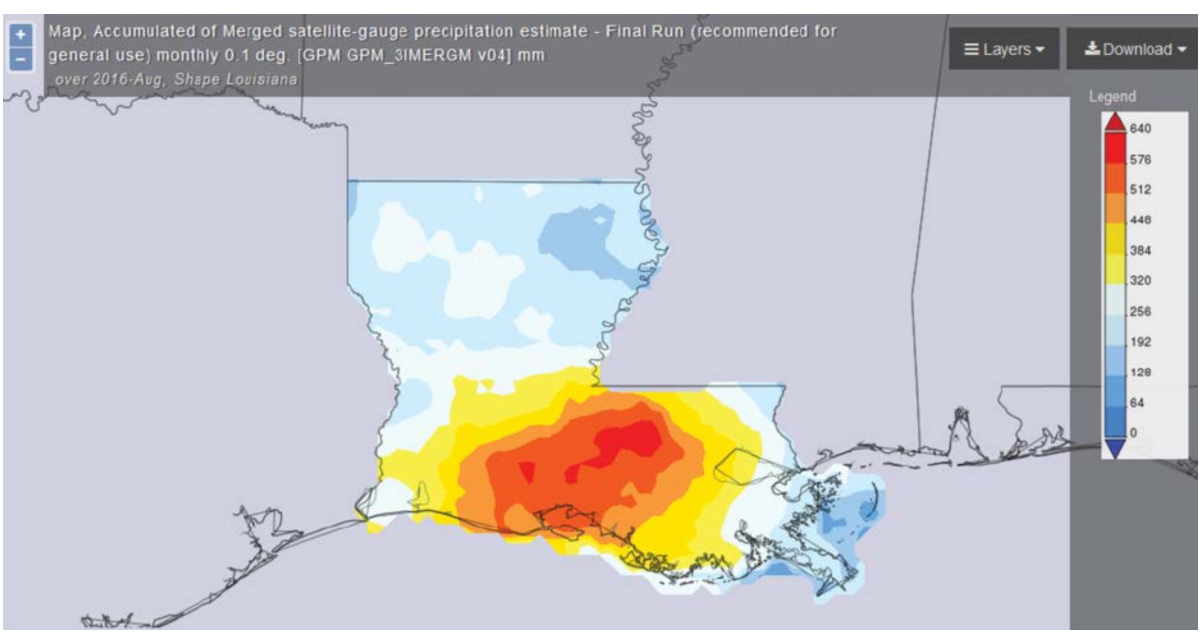


Fig. 3. Accumulated rainfall (millimeters) from GPM Integrated Multisatellite Retrievals (IMERG) Final Run (version 4), showing a record-breaking flood event in Louisiana in August 2016. Credit: Giovanni

example, a search for "precipitation" returns more than 100 related variables. A user performing a faceted search can filter for variables based on satellite missions (TRMM, Global Precipitation Measurement (GPM)), instruments, spatial or temporal resolution, or other categories.

The operating lifetimes of low-Earth-orbiting satellites are often quite limited (on the order of 5 years), far less than the 30 years recommended by the World Meteorological Organization for developing climatology data sets. Some users, however, may still wish to conduct preliminary studies with these satellite data sets to obtain information on spatial distribution and interseasonal variation. Giovanni provides the capability to derive climatologica l maps and time series based on user-defined time periods.

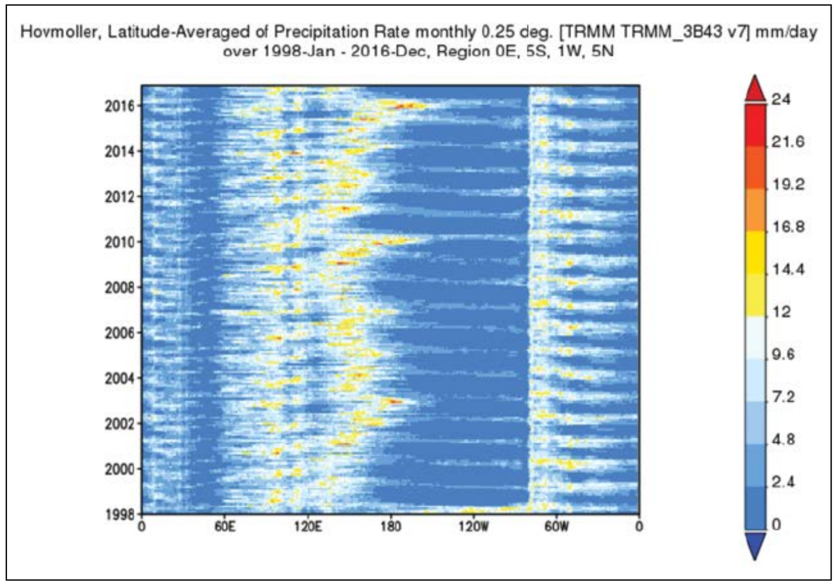


Fig. 4. Hovmöller diagram of TMPA monthly precipitation (millimeters per day) in the tropical region (5°S–5°N) showing El Niño–Southern Oscillation events between 1998 and 2016. Credit: Giovanni

Analytical Features

Giovanni includes many commonly used analytical and plotting capabilities for capturing spatial and temporal characteristics of data sets. Mapping options include time averaging (Figure 2), animation, precipitation accumulation (Figure 3), time-averaged overlay of two data sets, and user-defined climatology. For time series, options include area averaged, differences, seasonal, and Hovmöller diagrams (Figure 4).

Cross sections, applicable to 3-D data sets from NASA's Atmospheric Infrared Sounder (AIRS) instrument and Modern-Era Retrospective Analysis for Research and Applications (MERRA) data analysis program, include latitude-pressure, longitude-pressure, time-pressure (Figure 5), and vertical profile.

For data comparison, Giovanni has built-in processing code for data sets that require measurement unit conversion and regridding. Commonly used comparison functions include map and time series differences, as well as correlation maps and *X*-*Y* scatterplots (area averaged or time averaged). Zonal means and histogram distributions can also be plotted.

Visualization Features

Visualization features include interactive map area adjustment, animation, interactive scatterplots, data

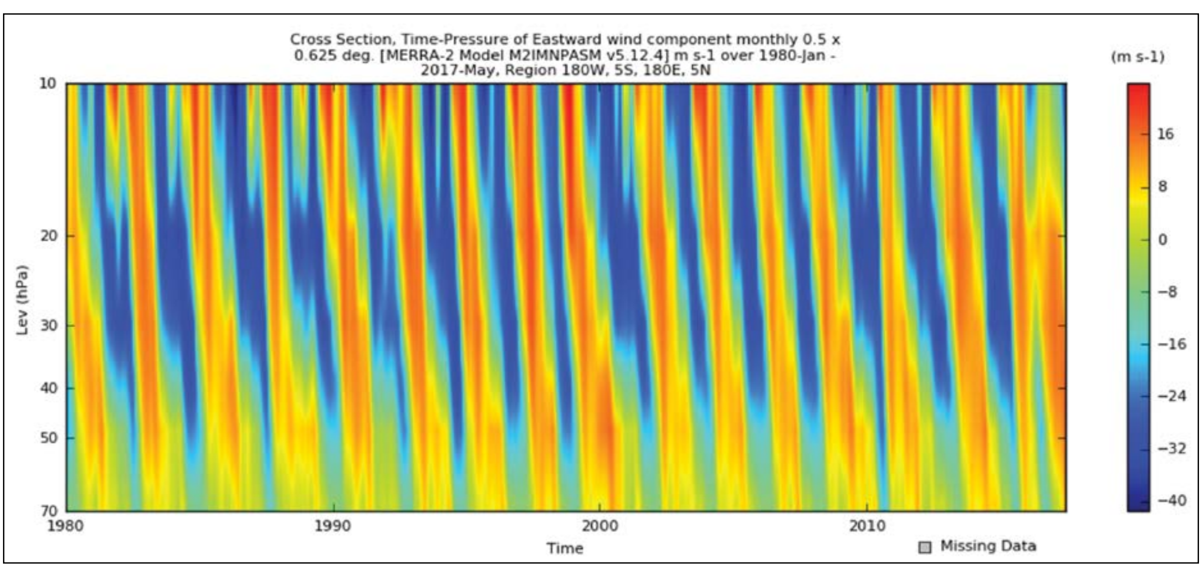


Fig. 5. Quasi-biennial oscillation (QBO) seen from the Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2), between 1980 and 2017. Credit: Giovanni

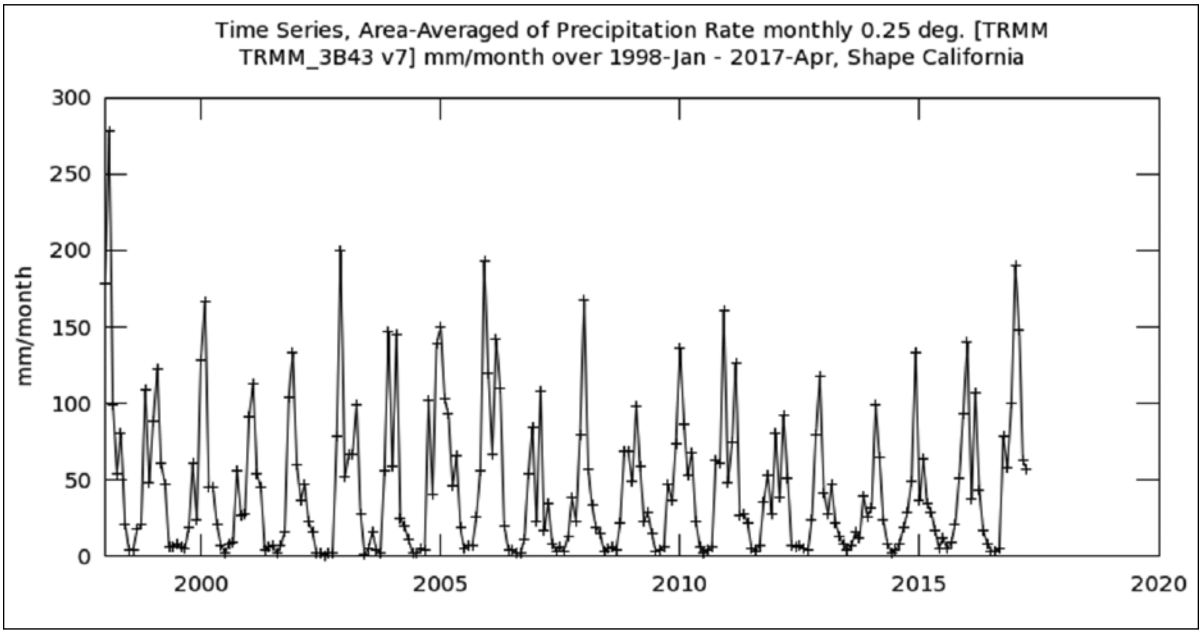


Fig. 6. Time series of area-averaged TMPA monthly precipitation (millimeters per month) for California, showing record-breaking droughts (2012–2015), followed by 2016–2017, the wettest winter ever recorded in northern California. Credit: Giovanni

range adjustment, choice of color palette, contouring, and scaling (linear or log). The on-the-fly area adjustment feature allows a user to examine a results map interactively and in detail without replotting data.

Giovanni also provides animations, which are helpful for tracking the evolution of an event or of seasonal changes. Interactive scatterplots allow identification and geolocation of a point of interest in a scatterplot. Adjustments of any of these plots provide customized options to users.

Formats Facilitate Many Applications

To support increasing socioeconomic and geographic information system (GIS) activities in Earth sciences, we have added shapefiles (a geospatial vector data format) for countries, states in the United States, and major watersheds around the world. Available functions for these shapefiles are time-averaged (Figure 2) and accumulated maps, area-averaged time series (Figure 6), and histograms. Land-sea masks have recently been added.

All data files involved in Giovanni processing are listed and available for download in the lineage page generated simultaneously with the visualization. Available output image formats are PNG, GeoTIFF, and Keyhole Markup Language (KMZ), and they can be used for different appli-

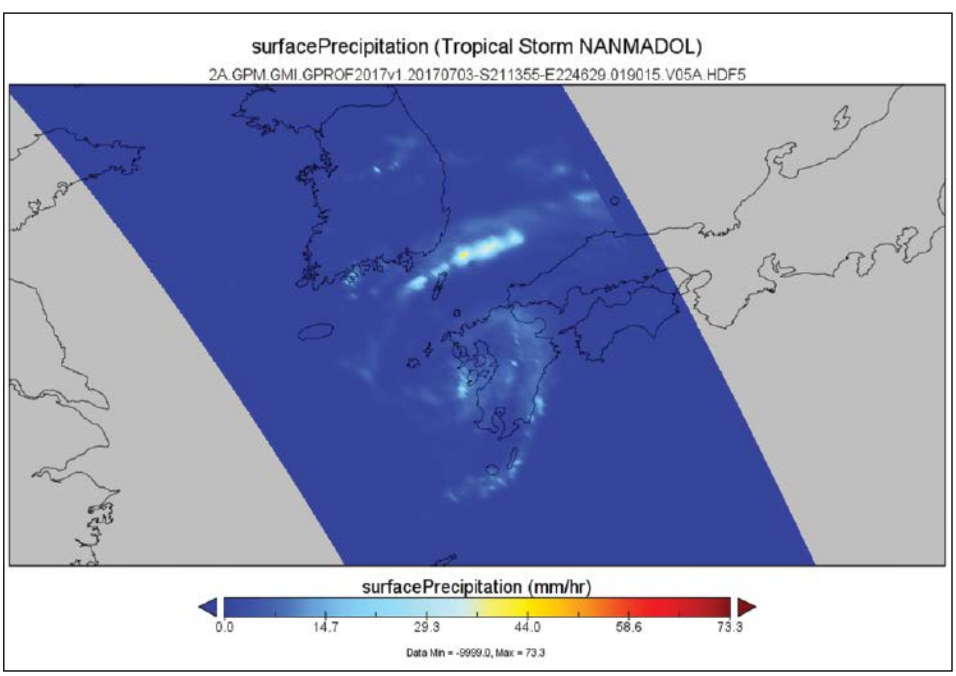


Fig. 7. A sample of satellite orbital data sets from GPM's Microwave Imager (GMI) showing surface precipitation of Tropical Storm Nanmadol on 3 July 2017. Credit: NASA Panoply

cations and software packages. For example, KMZ files are conveniently imported into Google Earth, where a rich collection of overlays is available.

All input and output data are available in the Network Common Data Form (NetCDF) formats, which can be handled by many off-the-shelf software packages. Furthermore, users can bookmark URLs generated by Giovanni processing for reference, documentation, or sharing with other colleagues.

Future Plans

With the latest features and applications, Giovanni simplifies accessing, evaluating, and exploring NASA satellite data sets. Despite these achievements, we still need to improve Giovanni to accommodate increasing demand for more analytical and plotting capabilities, more data sets, and advanced information technologies to make data exploration simple and productive.

Future plans include visualization and analysis of satellite orbital data sets (Figure 7), more data sets from other data centers, additional analytical methods and visualization, and analysis of multisatellite and multisensor measurements.

Data sets in Giovanni currently consist of variables mapped on uniform space-time grid scales, so nongridded or satellite orbital data sets remain largely untapped, even though they commonly provide higher spatial resolution. Adding orbital data sets to Giovanni could aid research requiring increased data resolution and coverage.

Data sets from other data centers and satellite missions will further enhance Giovanni for better understanding of Earth as an integrated system. Barriers still exist in the development of Giovanni for interdisciplinary studies and intercomparison among data sets. For example, terminologies in data sets can vary significantly between Earth science communities, requiring coordinated efforts to reach consensus and develop standards for uniform data products.

The NASA-wide User Registration System (URS) is also expected to enhance the Giovanni user experience. For example, with URS, users can set frequently used preferences in their profiles, record and retrieve their personal history of data set exploration, and establish their own data collections.

Data product developers can upload their test data and compare them with observations and other well-established data sets in Giovanni to identify issues in their products, a capability useful for improving data quality. Giovanni developers will also be able to better understand their users through profiles and other statistics collected from URS, so that they can develop more user-friendly services.

In summary, a wide variety of new features is available now in Giovanni, but it remains a work in progress. Creating a community tool with such a large scope is challenging, and fully realizing this tool requires active participation from the user community. We encourage users to provide their opinions as Giovanni continues to evolve.

Acknowledgments

We recognize the team effort of all past and current members at GES DISC for their contributions to the development of Giovanni. We extend our thanks to data set algorithm developers and many users for their feedback and suggestions. GES DISC is funded by NASA's Science Mission Directorate.

References

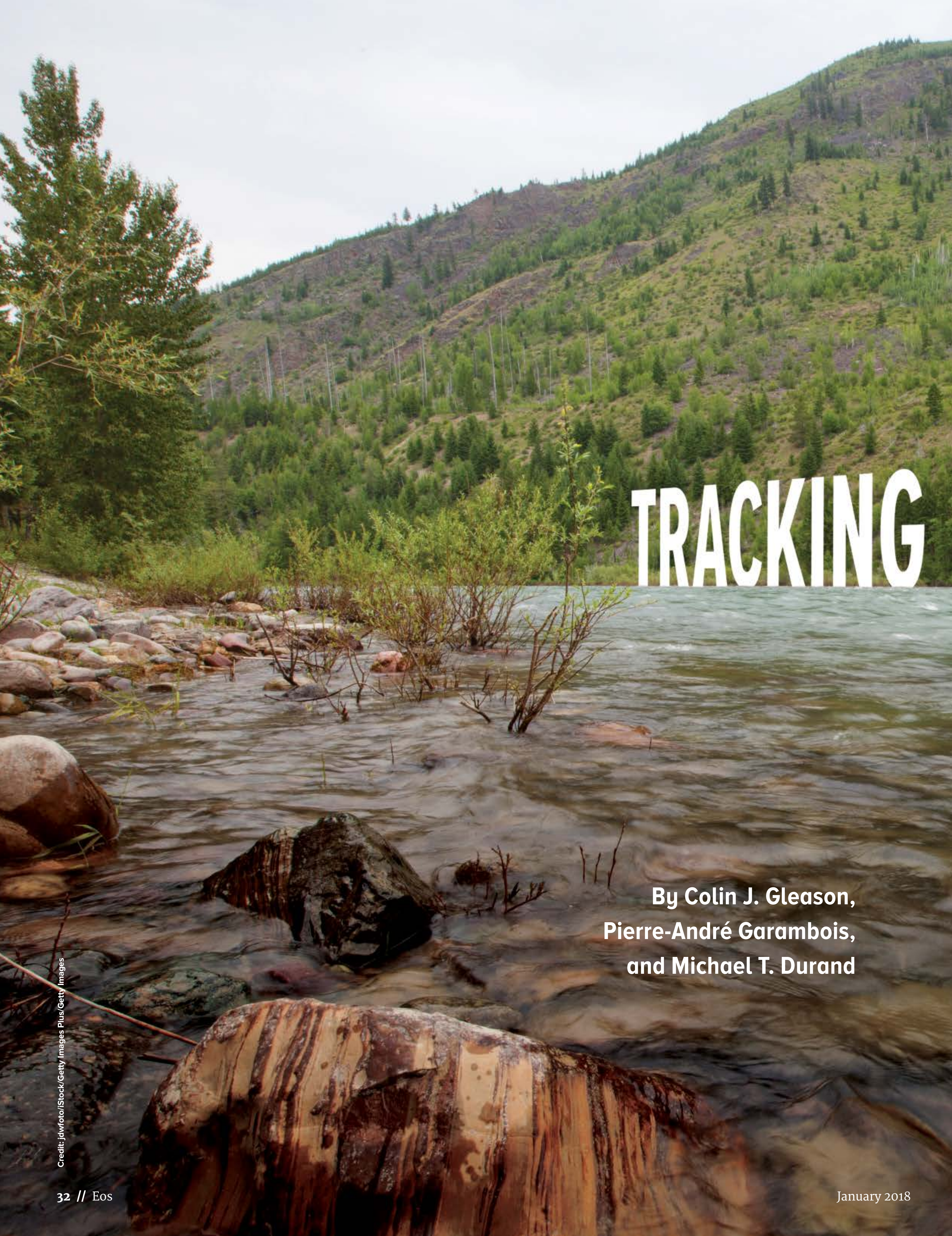
Acker, J. G., and G. Leptoukh (2007), Online analysis enhances use of NASA Earth science data, *Eos Trans. AGU, 88*(2), 14–17, https://doi.org/10.1029/2007EO020003.

Berrick, S. W., et al. (2009), Giovanni: A Web service workflow-based data visualization and analysis system, *IEEE Trans. Geosci. Remote Sens., 47*(1), 106–113, https://doi.org/10.1109/TGRS.2008.2003183.

Liu, Z., et al. (2007), Online visualization and analysis: A new avenue to use satellite data for weather, climate, and interdisciplinary research and applications, in *Measuring Precipitation from Space: EURAINSAT and the Future, Adv. Global Change Res. Ser.,* vol. 28, edited by V. Levizzani et al., pp. 549–558, Springer, New York, https://doi.org/10.1007/978-1-4020-5835-6.

Author Information

Zhong Liu (email: zhong.liu-1@nasa.gov), NASA Goddard Earth Sciences Data and Information Services Center, Greenbelt, Md.; also at George Mason University Center for Spatial Information Science and Systems, Fairfax, Va.; and **James Acker,** NASA Goddard Earth Sciences Data and Information Services Center, Greenbelt, Md.; also at Adnet Systems, Inc., Bethesda, Md.



TRACKING

By Colin J. Gleason,
Pierre-André Garambois,
and Michael T. Durand

Credit: jdwfoto/iStock/Getty Images Plus/Getty Images

RIVER FLOWS FROM SPACE

Satellite observations, combined with algorithms borrowed from river engineering, could fill large gaps in our knowledge of global river flows where field data are lacking.

For hydrologists, everything begins with water. This essential resource drastically alters the land surface and powers the basic cellular respiration underlying all living things.

When water falls on land and begins its slow passage to the ocean, its path almost invariably includes rivers, the most visible veins through which our planet's lifeblood courses. To best study freshwater systems, we need a fairly precise idea of how much water flows in Earth's rivers. You might think that we have this precise idea, right? Wrong.

Given the importance of water—especially river water—in ecosystems, industry, and agriculture, this lack of knowledge must be addressed. This issue is far more than academic: Well-documented issues of water data secrecy, toxic water politics, and even water conflict highlight the urgent need to better understand and monitor freshwater fluvial fluxes.

Field instruments provide accurate data that can span decades but only in the locations where they are installed. The data these instruments provide are available only from nations that choose to share them.

The Surface Water and Ocean Topography (SWOT) satellite mission, jointly developed by NASA, France's Centre National d'Etudes Spatiales (CNES), the Canadian Space Agency, and the UK Space Agency and scheduled for launch in 2021, aims to change how we assess freshwater export from rivers (see https://swot.jpl.nasa.gov). One mission objective explores a novel alternative approach that uses remote sensing data to estimate river fluxes.

The essence of our idea is simple: We use satellite observations of rivers, and we apply basic flow laws and

River water plays a crucial role in molding land formations like Watkins Glen, a popular hiking destination near Ithaca, N.Y., that offers a glimpse into the geologic past. McFLI techniques are new to hydrology, but they hold promise for closing gaps in our understanding of global freshwater. Credit: C. J. Gleason

the principle of mass conservation to work out what a river's discharge must have been to produce the observations. We refer to methods that take this approach as mass-conserved flow law inversion (McFLI) techniques.

Why Use McFLI?

The total amount of water on the planet measures to about 1.4 billion cubic kilometers, of which less than 1% is accessible freshwater [*Margulis,* 2016]. But we have a difficult time tracking the flux, or discharge, of water as it winds through rivers globally.

Hydrologists have been tracking river fluxes for decades using gauging stations, field instruments that record river depth and convert it to flux through an empirically calibrated rating curve. These stations are highly accurate, but they are expensive to install and maintain, and the supply of publicly available data is in decline in some parts of the world for economic and political reasons [*Hannah et al.,* 2011].

We apply basic flow laws and the principle of mass conservation to satellite observations to work out what a river's discharge must have been.

How, then, can we set some bounds on the total amount of freshwater flowing through rivers? We could turn to macroscale hydrological modeling to predict river flows by using a water balance approach that considers river flux to be the result of precipitation, evapotranspiration, and other interactions. However, despite advances in satellite monitoring, more efforts are required to fully constrain state-of-the-art global and regional hydrological models and link observed data to distributed hydrological fluxes [*Hijmans et al.,* 2005; *Syed et al.,* 2009].

An approach like McFLI, which is indirect but based on physical flow laws, is needed because it is nearly impossible to directly measure river discharge remotely. Planes and satellites have an extremely difficult time seeing the bottom of a river through deep or murky water [*Legleiter et al.,* 2009]. But they can measure river width, surface height, and slope and how they change over time. McFLI takes these measurements and combines this information with flow physics laws to set bounds on water discharge without having to rely on direct measurements of depth.

McFLI's Approach to Modeling River Flows

McFLI methods start with an open-channel flow law, of which there are several common simplified versions in hydrology. Such empirical equations, often used in the field of river engineering, serve as the basis of McFLI methods for quantifying river fluxes.

A well-known example of a flow law is Manning's equation, which describes water velocity for free surface flows driven by gravity and includes an empirically calibrated flow resistance parameter. Another simple example is hydraulic geometry, which uses power law relationships to link width, depth, or velocity in a channel to discharge.

River flow models vary widely in their complexity, ranging from full expressions of conservation of mass and momentum in a river channel to simple, empirically derived equations that capture key flow parameters. At the same time, all such models face the significant difficulty of describing flow resistance: how much a channel slows down flow because of friction, meandering, and other losses.

Models require data; remote sensing provides some of these data, including observations of river width (but not depth). With McFLI, a few assumptions and the principle of mass conservation allow us to compute what the discharge must have been to produce the observed widths, slopes, and water elevation at the instant the observations were made from space.

The principle of mass conservation, applied to river channels, simply states that the amount of water entering and leaving a section of channel is the same. Although this assumption is patently false when considering entire river systems, it is approximately true when considering short sections of river (called reaches) that we are sure contain no tributaries, dams, sloughs, or significant groundwater exchanges.

Converting Satellite Observations to Discharge Estimates

McFLI methods are destined to play an important role in interpreting observations from the SWOT mission. With SWOT, we will be able to observe river width, surface slope, and water surface elevation simultaneously. Over time, this will allow us to track changes in a river channel's cross-sectional area, channel shape, and water surface slope as water levels go up and down.

To make estimates of river discharge using McFLI algorithms, we write a given flow law for river cross sections. These 2-D slices of a reach represent the basic hydraulic unit of consideration here.

Flow laws such as Manning's equation express river discharge in terms of a number of variables: the cross-sectional area of the river channel, an empirical measure of flow resistance, the hydraulic radius (which describes the shape of the channel), and the water surface slope at that cross section.

McFLI approaches search for the best fit cross-sectional area (keeping in mind that we can see changes in the area but not the total area itself), flow resistance, and discharge at each cross section through time such that mass and momentum are conserved. The resulting mathematical problem is not straightforward, and specialized stochastic (random variable) and deterministic (cause and effect) techniques are required to solve for discharge and calculate uncertainties.

Wanted: More Data

The key to the McFLI approach is thinking about rivers simultaneously in space and time worldwide. These techniques will allow us to estimate discharge in

The North Fork Flathead River represents the pulse of the changing cryosphere as it drains snowmelt and glacier melt from mountains in northern Montana and southern Alberta, Canada. Recent studies suggest that McFLI could prove to be the right tool to address significant deficiencies in our knowledge of global river water. Credit: M. T. Durand

ungauged basins, ones for which we have no in situ data. Doing this calculation for rivers around the world, in theory, could give us a good idea of how much water flows through rivers at any given moment.

So far, we have applied McFLI methods to short (10- to 80-kilometer) reaches on approximately 60 hydrologically and hydraulically diverse medium to large rivers. Results are encouraging: By using remotely sensed snapshots, we can actually see mass conservation in our target reaches, and by building a temporal archive of these snapshots, we are better able to estimate discharge.

Nonetheless, there is still room for improvement [see, e.g., *Durand et al.,* 2016]. We face the same political and economic barriers to testing and validating the McFLI approach as we do in measuring discharge globally without McFLI. It is also difficult to find longitudinal data sets (collected over long periods of time) of river height and width distributed across mass-conserved reaches to ground truth, develop, and test McFLI approaches.

The collection of these data (e.g., via an array of pressure transducers coupled with a bathymetry map) would greatly enhance McFLI research. Data are also needed on a diverse range of test cases to develop greater confidence in a McFLI algorithm's ability to estimate discharge in ungauged basins.

Three Challenges

McFLI techniques are still relatively new, but research on these methods is rapidly expanding. Furthermore, the launch of SWOT promises to usher in a new age of hydrology as the satellite's measurements, collected from a 21-day orbit, increase the information available from space [*Biancamaria et al.,* 2016].

Realizing this promise will require much work before and after the launch of SWOT. We see three key open challenges for the McFLI approach, and we hope that the hydrology community will join us in pursuing them:

- maximize the accuracy and robustness of McFLI algorithms by incorporating ancillary data from satellites, models, and in situ observations
- develop new McFLI techniques combining adapted flow laws and mathematical methods for inversions
- systematically test McFLI algorithms to define different inversion classes of rivers based on geography and available data, with well-understood error budgets for use in gauged and ungauged basins alike

Finally, McFLI is not intended to replace hydrologic modeling or gauge-based observations, and results indicate that there is room for McFLI's improvement. Indeed, its full potential can be reached only when McFLI is used together with models and gauges. Only then can we understand the water cycle with sufficient clarity to make informed water resources decisions at the global scale.

We hope that our efforts will inspire scientists across disciplines to develop new approaches and databases to accelerate our understanding of our most precious resource. Together, we can move closer to the elusive answer to that fundamental question: How much water courses through world rivers?

The Remote Sensing of Rivers and Lakes sessions (H42G, H43T, H44H, and H33F) at the 2017 AGU Fall Meeting in New Orleans, La. served as a focal point for the community. Those wishing to get involved are encouraged to contact the authors or review materials from those sessions (see http://bit.ly/Hydrology-FM2017).

Acknowledgments

We thank NASA, CNES, and all our colleagues from the SWOT science team for fruitful discussions and contributions to the ideas of McFLI, especially the contributions of Jerome Monnier, Helene Roux, Stéphane Calmant, Jean-François Crétaux, Larry Smith, Tamlin Pavelsky, and Paul Bates. Finally, we thank Ernesto Rodriguez for his seminal contributions to remote sensing of hydrology and, in particular, his mentorship of all of the authors of this article.

References

Biancamaria, S., D. P. Lettenmaier, and T. M. Pavelsky (2016), The SWOT mission and its capabilities for land hydrology, *Surv. Geophys., 37*(2), 307–337, https://doi.org/10.1007/s10712-015-9346-y.

Durand, M., et al. (2016), An intercomparison of remote sensing river discharge estimation algorithms from measurements of river height, width, and slope, *Water Resour. Res., 52,* 4527–4549, https://doi.org/10.1002/2015WR018434.

Hannah, D. M., et al. (2011), Large-scale river flow archives: Importance, current status and future needs, *Hydrol. Processes, 25*(7), 1191–1200, https://doi.org/10.1002/hyp.7794.

Hijmans, R. J., et al. (2005), Very high resolution interpolated climate surfaces for global land areas, *Int. J. Climatol., 25*(15), 1965–1978, https://doi.org/10.1002/joc.1276.

Legleiter, C. J., D. A. Roberts, and R. L. Lawrence (2009), Spectrally based remote sensing of river bathymetry, *Earth Surf. Processes Landforms, 34*(8), 1039–1059, https://doi.org/10.1002/esp.1787.

Margulis, S. A. (2016), *Introduction to Hydrology,* version 2016a, e-textbook, Univ. of Calif., Los Angeles, http://aqua.seas.ucla.edu/margulis_intro_to_hydro_textbook.html.

Syed, T. H., J. S. Famiglietti, and D. P. Chambers (2009), GRACE-based estimates of terrestrial freshwater discharge from basin to continental scales, *J. Hydrometeorol., 10*(1), 22–40, https://doi.org/10.1175/2008JHM993.1.

Author Information

Colin J. Gleason (email: cjgleason@umass.edu), Department of Civil and Environmental Engineering, University of Massachusetts Amherst; **Pierre-André Garambois,** ICube Laboratory, Fluid Mechanics Team, Department of Civil Engineering, Institut National des Sciences Appliquées de Strasbourg, Strasbourg, France; and **Michael T. Durand,** School of Earth Sciences and Byrd Polar and Climate Research Center, Ohio State University, Columbus

Medalists Honored at 2017 AGU Fall Meeting

Kopp, Lamb, Lavallée, Li, and Shaw Receive 2017 James B. Macelwane Medals

Robert E. Kopp, Michael P. Lamb, Yan Lavallée, Wen Li, and Tiffany A. Shaw were awarded the 2017 James B. Macelwane Medal at the AGU Fall Meeting Honors Ceremony, held on 13 December 2017 in New Orleans, La. The medal is for "significant contributions to the geophysical sciences by an outstanding early career scientist."

Robert E. Kopp

Citation for Robert E. Kopp

Dr. Robert E. Kopp is an outstanding young scientist who has already achieved a remarkable record of sustained research excellence in geobiology, climate policy, and sea level change. The James B. Macelwane Medal is intended to honor scientists who display exceptional depth and breadth of research. In this respect, Bob's research program is unprecedented. Bob is brilliant, quantitatively adept, extraordinarily collegial and collaborative, and focused on research, teaching, and public service.

Certainly, the impact and quality of Bob's publication record alone qualify him for the James B. Macelwane Medal, including one article on paleo–sea level that is, perhaps, the best and most original in its field in many, many years. Bob is the key inventor and innovator of Bayesian Gaussian process modeling of sea level, an application that has revolutionized the field of sea level rise reconstruction and projection. Beyond the high quality and sheer number of his scholarly contributions, Bob exemplifies many additional qualities that speak to his promise for continued leadership, including his talent as an educator—both within academia and beyond—and as a leader in interdisciplinary science teams. Bob has built a highly successful research group at Rutgers, and he did so at an impressive speed. There is no doubt that Bob already has had a significant impact on training scientists of the future.

Bob's continued engagement in policy and outreach—such as working with individual states on sea level risk analyses and coauthoring technical aspects of the excellent Risky Business reports to the National Academy of Sciences and the Intergovernmental Panel on Climate Change—illustrates his ability to make contributions in diverse areas of climate science and communicate his scientific expertise into relevant policy advice. His service record would be exemplary for a senior scientist; for an early-career researcher, it is truly remarkable.

I would like to conclude by saying that Bob has emerged as one of the most energetic and productive scientists of his generation. His accomplishments as a scholar, educator, and citizen of AGU's academic community make him more than deserving to receive the James B. Macelwane Medal. Please join me in congratulating Dr. Robert E. Kopp on his accomplishments.

—**Benjamin P. Horton**, *Asian School of the Environment, Nanyang Technological University, Singapore*

Response

Thank you, Ben, for the nomination, and thanks to AGU for this great and humbling honor.

My career has depended intensely on the support of family, friends, mentors, and collaborators. My parents fostered a love of inquiry and provided boundless support. David Morrow, my longest-standing collaborator, has exchanged ideas with me since middle school. At the University of Chicago, Munir Humayun brought me into geosciences by way of astrobiology and let me work with a tiny piece of Mars. At the California Institute of Technology (Caltech), Joe Kirschvink brought me to his quirky Earth, taking me around the world to study the Precambrian rise of oxygen and the fossils of magnetotactic bacteria. At Princeton, Adam Maloof dove with me into the weird North American coastal waters of the Paleocene–Eocene Thermal Maximum, Frederik Simons helped me hone my statistical skills, and Michael Oppenheimer grounded me in the challenges that arise when humans start tinkering with the Earth system. During my first venture outside of academia, Rick Duke gave a policy-inexperienced young scientist the challenge of helping the U.S. government figure out how to value climate damages.

For the last 7 years, my colleagues at Rutgers have been great supporters and collaborators. From unearthing and interpreting paleo–sea level records to building coastal resilience in the aftermath of Hurricane Sandy, I've been in the right place and time to work with colleagues like Ben Horton and Ken Miller and outstanding students and postdocs on both the fundamentals and the applications of sea level science. I've come into the paleo–sea level community at a time when that community, through PALSEA, has been organized into one of the most welcoming and collegial small scientific associations I've ever encountered. I've been extremely fortunate to have worked over the last 4 years with outstanding economists like Solomon Hsiang to build the multi-institutional collaboration that is now the Climate Impact Lab. To top it off, most recently, I've been blessed to have met my wonderful, compassionate, supportive wife, Farrin Anello. And there are so many more family members, friends, and colleagues I'd like to thank but cannot name.

I'd like to express my appreciation to AGU for valuing the winding road I've taken. I'd like to accept this award on behalf of all the young scientists in our community who are trying to be both excellent researchers and active participants in addressing the societal challenges revealed by the geosciences.

—**Robert E. Kopp**, *Institute of Earth, Ocean, and Atmospheric Sciences, Rutgers University–New Brunswick, N.J.*

Michael P. Lamb

Citation for Michael P. Lamb

Michael Lamb's research activities and his influence on other geoscientists are together transforming studies of land-forming mechanisms and their sedimentary record in terrestrial, submarine, and extraterrestrial landscapes. With his students and postdocs he has opened up new avenues of research by tackling head-on long-standing, unresolved questions through theory, field observation, experimentation, and numerical simulation. The results are striking advances in the understanding and modeling of landscape-shaping mechanisms in mountainous terrain and on alluvial plains and deltas, the seafloor, and extraterrestrial bodies.

Remarkably, Mike has already made fundamental contributions in multiple fields: geomorphology, sedimentology, and planetary science. His work has deepened our understanding of river incision in mountainous landscapes, including the roles of sediment transport, megafloods, and waterfall genesis, with implications for interpretation of landforms on Earth and Mars. He has fundamentally changed our understanding of the transport of large clasts by rivers, demonstrating and explaining the nonintuitive finding that higher fluid shear stresses are required for clast transport on steeper slopes. On continental margins, Mike has significantly advanced understanding of coastal alluvial rivers and their linkage to sedimentation in the nearshore environment and their role in the development of seafloor stratigraphy and bed forms. He has extended his work on sedimentary bed forms to include extreme environmental conditions experienced during Snowball Earth or on Mars; his work augments the capacity to interpret environmental conditions recorded by landforms, sediments, and bed forms throughout the solar system.

The powerful guiding approach in all these advances is the integration of physical insight, critical field observations, innovative experimentation, and numerical simulation with the development of parsimonious theories of the behavior of flows, granular disturbance transport processes, geotechnical material properties, and their geomorphic or sedimentary products. Mike had the foresight and fortitude to build an extraordinary experimental flume—one with the capacity to enable the extreme experiments required to test and elaborate his early theoretical ideas on river incision by suspended particles, erosion by waterfalls, and initiation of motion of large clasts in steep rivers. The risk has paid off handsomely.

Mike is an avid and effective collaborator, generous with his time and in granting credit to others. His creativity is widely felt, is generously shared, and has already begun to generate a stream of inspired and well-trained students and postdocs who have embarked on their own productive research careers. Mike is destined to have a singular impact

on the study of landscape evolution on Earth and other planetary bodies.

—**Kelin X. Whipple**, *Arizona State University, Tempe*

Response

Thank you, Kelin, for those overly kind words and thanks to Tom Dunne, John Grotzinger, and Alan Howard for your nomination. I am honored to be recognized by AGU and to be part of the generous community of Earth surface processes. It is sharing ideas with students, mentors, and colleagues that renews my curiosity and drive. And it certainly helps to work in a discipline that is realizing major discoveries about Earth's dynamic surface. There are many people to thank.

It is my good fortune, being Minnesotan, that my local university hired a captivating and well-bearded instructor, Chris Paola. Chris inspired me to switch majors from engineering to geology and pursue graduate school. He also introduced me to Gary Parker, and I am grateful to Gary for leading me through my first scientific investigation and his continuing mentorship and intellectual generosity. I am indebted to Bill Dietrich, my Ph.D. adviser, for teaching me how to interrogate the Earth with new eyes and giving me the tools to be a scientist. As I was leaving Berkeley, Bill told me, while eating nuts, to be curious, question everything, and take notes, and, Bill, I try my best to do the first two. Alan Howard is my example of a modern-day explorer, and Jeff Parsons helped me navigate turbulence. I am continually inspired by Paul Myrow, who taught me, among other things, that fieldwork is always fun regardless of itchy skin. And I always find myself trying to mimic David Mohrig, not in wardrobe but in time travel between modern and ancient environments. Acknowledging others requires cheating the word limit: PerronVendittiNittrouerFischerTsaiMcElroyEwing-DiBiaseGantietal.

I enjoy my job, and I feel very fortunate to be able to say that. At the California Institute of Technology (Caltech), it has been a great pleasure to have worked with many brilliant students, postdocs, and colleagues in an extremely engaging, challenging, and fun environment. This award reflects our collaborative work. Brian Fuller brought flume experiments back to Caltech, and John Grotzinger has broadened my thinking and taught me to shoot with both eyes open. I look forward to years to come.

Although my parents still think I am an engineer, I thank them for always encouraging me. And most important, I simply would not have survived the trials of tenure without the love and friendship of my wife, Anna, and hugs from our amazing girls, Evelyn and Rhea.

—**Michael P. Lamb**, *California Institute of Technology, Pasadena*

Yan Lavallée

Citation for Yan Lavallée

Professor Yan Lavallée is recognized for his innovative high-temperature experimentation in the solid Earth sciences. His laboratory is devoted to experiments performed at the extreme conditions relevant in volcanic systems. The experiments are designed to advance understanding of volcanic, geothermal, and other dynamic geological processes. His research program leads the world in elucidating linkages between magma properties and rheology and the behavior (explosive versus effusive) of volcanic systems.

Lavallée obtained his B.Sc. honors degree from McGill University in Canada, and his early research involved analogue modeling of caldera subsidence. He continued his research on calderas with a study of a Peruvian volcano to earn his M.Sc. in space studies at the University of North Dakota in the United States. His passion for high-temperature experimentation, however, derives from his Ph.D. studies at Ludwig Maximilian University in Munich, Germany.

His Ph.D. studies focused on lava dome–producing volcanoes; these eruptions are unpredictable and can rapidly switch from quiescent effusive behavior to catastrophic explosive activity. Understanding the switching mechanisms has been a topical line of research for 20+ years. Lavallée has provided a quantitative understanding of how the porosity, permeability, and crystallinity of dome magmas affect rheology and, together with effusion rates, dictate volcanic consequences. His experimental data on crystal-rich dome lavas demonstrated the non-Newtonian strain rate dependence of magma viscosity and showed the commonly employed Einstein–Roscoe equation to be totally inappropriate for crystal-rich magmas. This result launched an industry of studies into the effects of crystals and bubbles on magma rheology. His work also made connections between field observations on lava domes, experimental deformation of natural dome magmas, and geophysical signals expressed in nature and captured in the lab. His insightful analysis of these data sets produced a means of forecasting lava dome collapse events based on seismic signals.

Lavallée is now a professor of volcanology in the Department of Earth, Ocean and Ecological Sciences, where he has established a vibrant, well-equipped (approximately US$2.5 million) laboratory for experimentation on volcanic materials. Recent high-impact studies have explored the interplay of frictional heating and vesiculation, suggesting that thermal heating may play a larger role in explosive eruptions than previously recognized. His experiments also explored the capacity of "tuffisite networks" (veins of pyroclastic particles) within lava domes to control permeability and thus explosivity. His experiments showed how the timescale of "healing" of the tuffisite veins provides a means of transitioning to, and cycling between, effusive to explosive eruption by gas repressurization. Lavallée has made, and will continue to make, high-impact, important contributions to our understanding of volcanic processes through thoughtful experimentation.

—**Kelly Russell**, *University of British Columbia, Vancouver, Canada*

Response

It is with great gratitude that I receive the James B. Macelwane Medal; I extend my thanks to Kelly and my nominators, who certainly expressed generous words in favor of my contributions to geophysical sciences! I am most delighted to accept this prestigious honor and humbly stand alongside the illustrious scholars who have received it before me.

I was 5 years of age when, one summer afternoon in the province of Quebec, I asked my mother, "Maman, qu'est ce qu'on est?" Gobsmacked, she knew very well that the question I (and I imagine many of you) was troubled with could not be answered, at least, not simply. She looked at me, shrugged her shoulders, and replied that she didn't know. That initiated my search for answers—answers I sought in geosciences. It's been nearly 20 years since I began to study the Earth, and I count myself lucky to have faced very few problems that have cast a shadow large enough to darken a week at work. We're privileged in that we get to see the world through our work, and we all agree, it's a wonderful place, well worth knowing.

In my career to date, I have had the rewarding opportunity to work with well over 100 collaborators—in laboratories, at observatories, in factories, and everyone I met in the field—so I may not be able to thank all of you here, but please see these words as a kind reminder of the superb times we have spent together and of the findings we have achieved together. You have contributed in a million ways, and I share this honor with you.

My undergraduate years at McGill University taught me that everything can be achieved with dedication, hard work, and, of course, fun! Thanks to John Stix, Ben Kennedy, Alain Garand, and Don Francis for teaching me that important bit of wisdom, mixed with a great deal of geology! During my master's degree in space studies at the University of North Dakota, I was lucky enough to work alongside great mentors, Shanaka de Silva, Bob Andres, Mike Gaffey, Stephen Johnson, and Jeff Byrnes, who taught me as much about being a versatile and balanced scientist as about volcanoes, space, and history.

During my doctoral studies at the Ludwig Maximilian University in Munich, Germany, the field of geosciences exploded before my eyes. The technological revolution we are now witnessing has opened up countless possibilities, and I feel fortunate to have met a body of scientists to undertake work on the new challenges of modern volcanology. First, thanks to Don Dingwell for providing the best supervision and mentoring I needed: I owe the vast majority of my knowledge about life as an academic to you, a true friend and a great inspiration! Thanks also to the many I met in my time in Munich: Ulli Kueppers, Kai-Uwe Hess, Betty Scheu, Basti Müller, Jon Castro, Hugh Tuffen, Alex Nichols, Oliver Spieler, Jeremie Vasseur, Fabian Wadsworth, and many more.

In 2012, I moved to the University of Liverpool and established the Experimental Volcanology and Geothermal Research Laboratory to discover that even "Eight Days a Week" (as put forth by the Beatles) were not enough to maximize the scientific opportunities that were yet again growing in number. I thank Felix von Aulock, Silvio de Angelis, and more colleagues in the Faculty of Science and Engineering than I can begin to mention.

I would also like to take the opportunity to thank all those who push larger-than-life initiatives in geosciences, in particular, the Krafla Magma Testbed; I'm proud to be among such company as we aim to establish the first magma observatory. It is a reminder that "the wall between reality and fantasy is sometimes so small and not so tall" when we collectively join efforts for the advancement of our field (as pondered by Raphael Gualazzi in "Reality and Fantasy").

Finally, a very sincere thanks to my partner, Jackie Kendrick, whom I'm fortunate enough to work alongside. And thanks to all of my friends and family, scattered around this beautiful Earth.

In closing, many thanks to the AGU community for this heart-warming honor. In return, I promise to keep you entertained by publishing science as provocative as it is insightful and inspirational for many years to come.

—**Yan Lavallée**, *University of Liverpool, Liverpool, U.K.*

Wen Li

Citation for Wen Li

Wen Li has published several outstanding research papers showing how wave–particle interactions play a key role in controlling the dynamic evolution of the Earth's Van Allen radiation belts. She has pioneered the use of low-altitude satellite data as a proxy for the global distribution of plasma waves at much higher altitudes.

Wen Li started her work on the Earth's radiation belts as a Ph.D. student at the University of California, Los Angeles. One of her greatest achievements is to show that a particular class of plasma waves, known as electromagnetic ion cyclotron waves, can cause rapid loss of relativistic electrons that are otherwise trapped inside the external magnetic field of the Earth, a region known as the Van Allen radiation belts. She showed that most of the losses occur during the main part of a geomagnetic storm and that later on, as conditions recover from the storm, there is another class of plasma waves that can accelerate electrons to relativistic energies. Thus, she was able to show how wave–particle interactions play a key role in controlling the dynamic variability of the belts.

In order to quantify acceleration and loss on a global scale, one needs to know the global distribution of plasma waves. However, the properties of these waves vary considerably in space and time, making this a challenging problem. Wen Li developed a novel technique of using particle data from satellites in low-Earth orbit to calculate the properties of plasma waves along the geomagnetic field near the equatorial region. Because there are several satellites in low-Earth orbit, Wen was able to develop a global distribution of plasma waves with much higher spatial and temporal resolution than ever before. This technique has been adopted by other research groups and incorporated into global radiation belt models, which have shown a vast improvement. Wen's work has had a major impact and illustrates her creativity and lateral thinking.

Wen Li has published 120 papers, including 2 in *Nature* and 1 in *Science.* This is astonishing for an early-career scientist with only 7 years since her Ph.D. She is a member of the NASA Time History of Events and Macroscale Interactions during Substorms (THEMIS), Van Allen Probes, and now Juno mission science teams, and collaborates widely.

Wen Li has recently taken up a new position as assistant professor at Boston University. She is a shining example of excellent research, international collaboration, and leadership for the next generation.

—**Richard Horne**, *British Antarctic Survey, Cambridge, U.K.*

Response

I would like to thank Richard Horne for his generous citation and nomination. I am deeply grateful to Vassilis Angelopoulos, Mary Hudson, and Craig Kletzing for their strong support in this nomination process. I also really thank the Macelwane Medal Committee and AGU for this distinct honor.

My career has significantly benefited from support and encouragement from many of my dear colleagues, to whom I can never express my gratitude sufficiently. As a student, I was very fortunate to work under the guidance of professors who are passionate and dedicated to research and teaching: my Ph.D. adviser, Richard Thorne, at the University of California, Los Angeles (UCLA), and my undergraduate adviser, Youqiu Hu, at the University of Science and Technology of China. They taught me how to have fun in the wonderful world of space physics with their keen scientific insight, enthusiasm for science, and great sense of humor in life.

My Ph.D. research at UCLA started when the new NASA THEMIS mission led by Vassilis Angelopoulos was launched. The THEMIS mission opened the door for me to learn how to find and solve interesting scientific problems from the satellite data. Over this period, I also received generous help from the theoreticians and modelers, particularly Richard Thorne, Richard Horne, Jacob Bornik, and Yuri Shprits. During my postdoctoral research, I was truly fortunate to work on the Van Allen Probes data with many excellent team members, particularly Mary Hudson and Craig Kletzing, who have been warmly supporting my career development. My early career at UCLA greatly benefited from an extremely productive research atmosphere by working with my outstanding colleagues and friends, particularly Jacob Bortnik, Qianli Ma, Lunjin Chen, Zin Tao, and Binbin Ni, as well as many other colleagues with whom I have had a chance to work.

I am also really grateful to my colleagues at Boston University, who are very supportive of my research and teaching in the present early stage of my career as a faculty member by sharing their valuable experience and providing insightful suggestions. It has also been a great pleasure to work with my dear students and postdocs at Boston University, and I believe the best is yet to come.

Finally, I would like to give my special thanks to my family, in particular, my dearest colleague and husband, Toshi Nishimura, who was a recipient of the Macelwane Medal last year, for sharing numerous precious moments with me both academically and personally.

—**Wen Li**, *Boston University, Boston, Mass.*

Tiffany A. Shaw

Citation for Tiffany A. Shaw

Tiffany Shaw has done fundamental work explaining the atmospheric dynamics of tropospheric and stratospheric processes using a combination of numerical modeling, basic theory, and analysis of observations. Her work has had a broad impact beyond atmospheric dynamics, including improving global climate models, which are used in climate, paleoclimate, planetary science, and exoplanet research, and explaining important aspects of the Indian monsoon and jet streams, which are important for agriculture, geology, and geochemistry.

Tiffany began her career studying mathematics and atmospheric sciences at the University of British Columbia. She then did her Ph.D. in physics at the University of Toronto under the guidance of Ted Shepherd. Her Ph.D. contribution included theoretical developments related to gravity wave drag parameterization that have helped improve global climate models. Her key physical insight was that the middle atmosphere is driven by nonlocal wave forcing and is connected through it, so that violating momentum conservation can have grave, unintended consequences on the modeled circulation.

Tiffany then spent time as a research assistant professor at New York University and then as a postdoc and assistant professor at Columbia. During her time in New York, she improved our understanding of stratosphere–troposphere coupling and its role in tropospheric climate variability and anthropogenic climate change. She also advanced our understanding of tropospheric moisture and momentum transport between the tropics and the midlatitudes, especially in relation to stationary eddies and the rapid onset of the monsoon.

Since 2015, Tiffany has been on the faculty at the University of Chicago, where she recently received tenure. Here she has continued to branch out from the stratosphere to the troposphere and from the midlatitudes to the tropics. It is now fair to say that Tiffany has made significant contributions to nearly every major area of atmospheric dynamics.

Tiffany's approach to problems has included abstract mathematical manipulation and interpretation, clever use of global climate models, and careful analysis of observational data. She has dirtied her hands with projects that had appeared too messy to many atmospheric dynamicists and has solved problems that not only have beautiful solutions but also are interesting to a wide community of researchers working in climate and other areas. Her work has already had a tremendous impact, and it will continue to do so for years to come.

—**Dorian S. Abbot**, *University of Chicago, Chicago, Ill.*

Response

Thank you, Dorian, for your kind words. It's been a pleasure to be your colleague these past few years, and I look forward to many more. At the University of Chicago, I've become a better scientist because I've been pushed to ask big questions.

I'm truly grateful to AGU for this honor. Many people have contributed to my success, and I would like to thank each in turn. I would like to begin by thanking my collaborators, postdocs, and students for joining my quest. I share this award with you.

As an assistant professor, I received invaluable support from my colleagues at Columbia University, in particular, from Professors Arlene Fiore, Lorenzo Polvani, and Adam Sobel. I doubt I would have received this award without their support.

As a postdoctoral fellow, I had the pleasure of working with Professor Olivier Pauluis and Dr. Judith Perlwitz. They expanded my horizons and got me thinking about important processes in the troposphere.

In the very beginning I was fortunate enough to be advised by Professor Ted Shepherd at the University of Toronto. I owe much of my scientific rigor and intuition to him. He instilled in me the importance of using theory for its own sake as well as for practical purposes, for example, to improve climate models.

Finally, I want to thank my family, especially my newborn son, Henry. I look forward to exploring science and the humanities and sharing my future discoveries with you.

—**Tiffany A. Shaw**, *University of Chicago, Chicago, Ill.*

Mary K. Hudson Receives 2017 John Adam Fleming Medal

Mary K. Hudson was awarded the 2017 John Adam Fleming Medal at the AGU Fall Meeting Honors Ceremony, held on 13 December 2017 in New Orleans, La. The medal is for "original research and technical leadership in geomagnetism, atmospheric electricity, aeronomy, space physics, and/or related sciences."

Mary K. Hudson

Citation

Mary K. Hudson, AGU Macelwane medalist and Fellow, is, without peer, a leading international expert in theoretical studies and understanding of Earth's radiation belts and space plasma environment. Mary Hudson's research productivity and versatility in a wide range of space plasma topics and her outstanding service to the space physics research community amply qualify her to be the 2017 AGU Fleming medalist.

Early in her career Mary made significant contributions to theoretical studies of plasma processes and instabilities in Earth's ionosphere. These included a novel tackling of the spread *F* problem, the existence of which produces (among other deleterious effects) scintillations and outages in communication satellite signals.

The existence of signals in the ultralow-frequency band in Earth's magnetosphere has been investigated almost since the advent of sensitive magnetic field–measuring instruments in the 19th century. Mary recognized early the importance of these waves for affecting radiation belt dynamics and effectively created a new area of radiation belt research. Seminal theoretical and computer modeling work by Mary (including guidance of her students and colleagues) elucidated the fundamental importance of these waves for the transport and energization of trapped particle radiation.

As co–principal investigator (co-PI) for two of the five instruments on each of the dual Van Allen Probes (VA Probes) spacecraft and as co-PI for the NASA Balloon Array for Radiation-belt Relativistic Electron Losses (BARREL) studies of precipitating electrons, she has provided the essential underlying theoretical and modeling expertise to these projects, as well as to the entire VA Probes program. Her leadership participation has been essential for interpretation and major advances in understanding.

Mary has unselfishly served the space research communities in numerous significant capacities. These include as co-PI for the decade-long National Science Foundation (NSF) Science and Technology Center CISM (Center for Integrated Space Weather Modeling). She served as chair of the NSF Geospace Environment Modeling (GEM) Steering Committee. Mary served exceptionally well as cochair of the National Academies of Sciences, Engineering, and Medicine Committee on Solar and Space Physics. In the AGU family, Mary served on the Education Committee of the Space Physics and Aeronomy section and as secretary of the section. Very importantly, in her professional career at Aerospace and in her several academic positions (including a tenured endowed position at Dartmouth) she has served unselfishly (and often unheralded) as a strong mentor and a talented role model for women physicists and women in technical responsibilities.

—**Louis J. Lanzerotti**, *New Jersey Institute of Technology, Newark; also at Alcatel-Lucent Bell Laboratories, Murray Hill, N.J.*

Response

It is my great honor to receive this award around the 60th anniversary of the launch of the first "artificial satellites," as they were called, Sputnik 1 on 4 October 1957 and Explorer 1 on 31 January 1958, first reporting the Van Allen radiation belts. I have had the privilege of studying these in recent years using remarkable data from the NASA Van Allen Probes. I began two solar cycles prior when the Sun changed our view of static radiation belts and space weather emerged as a growing concern in a world now connected by artificial satellites.

I became interested in space and the cosmos early because of the space race and my childhood telescope. I was fortunate to attend a great public university, the University of California, Los Angeles, and had the opportunity to work with pioneers in radiation belt studies at the Aerospace Corporation, George Paulikas and Bern Blake, and another radiation belt pioneer, Charlie Kennel, my thesis supervisor.

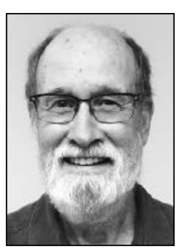
Arriving at the University of California, Berkeley in 1974, I was again fortunate when Forrest Mozer led the first electric field double-probe experiment to study processes that produce the aurora. A group of us including Bill Lotko, Bob Lysak, Ilan Roth, Cindy Cattell, John Wygant, and Mike Temerin—all barely 30—made a reputation for ourselves helping to explain the exciting S3-3 satellite observations

I might have stayed in the "auroral zone" had the opportunity not arisen for faculty positions at Dartmouth. My husband, Bill Lotko, and I are both greatly indebted to Professor Bengt Sonnerup, who encouraged a California native to make the leap to rural New Hampshire. I am grateful to numerous very talented students, postdocs, and senior colleagues who made the leap to the Granite State, as well as my funding agencies. It is a great pleasure to share this moment with many of you tonight. James Van Allen told me when he handed me the Macelwane award in 1984 that I was the first woman to receive it. I am most happy this is not the case for the Fleming—Janet! Grandma Sadie Martin "leaned in" a long time ago as one of only four women in her graduating class. Our two wonderful daughters, Lauren and Anna, are paving the way for granddaughters Sally and Maddie to aspire to anything they want to be. I thank them for the future and my husband, Bill Lotko, who has never wavered in his encouragement.

—**Mary K. Hudson**, *Dartmouth College, Hanover, N.H.*

Donald W. Forsyth Receives 2017 Maurice Ewing Medal

Donald W. Forsyth was awarded the 2017 Maurice Ewing Medal at the AGU Fall Meeting Honors Ceremony, held on 13 December 2017 in New Orleans, La. The medal is for "significant original contributions to the ocean sciences."



Donald W. Forsyth

Citation

Don has been a role model for me and for many of us in marine geophysics. I came to know Don through his pioneering work and his leading role in the Mantle Electromagnetic and Tomography (MELT) experiment, which transformed both marine seismology and our understanding of the melting processes beneath the ocean spreading centers. It was a technological breakthrough, which became a model for future marine seismology experiments. The MELT experiment demonstrated that the melt extends down to 150-kilometer depth and that the melting is asymmetric beneath the ridge axis.

While we were still admiring the results from the MELT experiment, Don led another important experiment, Gravity Lineations, Intraplate Melting, Petrology and Seismology Expedition (GLIMPSE), to study the origin of the linear chain of seamounts and volcanic ridges present only on the Pacific plate side orthogonal to the fast spreading East Pacific Rise. Based on the analysis of seismological, gravity, and bathymetry data, he challenged the existing model of the origin of these ridges by small-scale convection in the mantle and proposed a new model requiring viscous interfingering of enriched material from the mantle upwelling related to the superswell.

It seems that marine geophysics was natural to Don; he started making fundamental contributions during his Ph.D. and wrote a seminal paper on the relative importance of driving forces (ridge push and slab pull) of plate motion. This model helped him to quantify the oceanic mantle anisotropy due to plate motion as it cools away from the ridge axis. He was first to recognize the importance of plate bending in the outer rise leading to earthquake generation.

Don realized the importance of analyzing integrated seismological, gravity, and bathymetry data to determine the anisotropy structure of the Pacific upper mantle and the effective elastic thicknesses of the East African plate. Using gravity data, he discovered the idea of the mantle Bouguer anomaly, separating the effect of crustal thickness from the mantle, allowing us to identify the effect of mantle upwelling beneath ridge axes and plumes and downwelling, such as the Australia–Antarctica discordance zones. He also developed the concept of a bull's-eye at slow spreading centers.

My recent encounter with Don has been on the imaging of the oceanic lithosphere–asthenosphere boundary

(LAB), where he discreetly and humbly enlightened me with different conflicting models of the LAB. I would like to thank Don for providing leadership over the last 40 years and invite you to join me in congratulating him on receiving the 2017 Maurice Ewing Medal, a well-deserved honor.

—**Satish Singh**, *Institut de Physique du Globe de Paris, Paris, France*

Response

I'm honored to receive this year's Maurice Ewing Medal. It is a very nice semiretirement gift to receive as I embark on the emeritus phase of my research career. Thanks to AGU and the Office of Naval Research and, particularly, to those who wrote letters in support of my nomination.

This honor really should be a community recognition for all the infrastructure and technological advances developed by others that have made my research possible. Multibeam echo sounding reveals the basic seafloor structure, GPS allows us to actually know where we are, and satellite altimetry makes it possible to plan detailed surveys in advance. There have been great advances in ocean bottom seismographs that make probing the mantle beneath the seafloor possible with much better resolution. The Incorporated Research Institutions for Seismology data management center has made accessing and processing seismic data much easier. And, of course, none of this would have been possible without ships and their crews and technicians. The capability and comfort of research ships in the academic fleet have improved tremendously since my first cruise on the *Chain,* a converted minesweeper.

Almost all of my research has been done in close collaboration with students, postdocs, and other colleagues. It is totally unfair to single out just a few individuals among them, because they all contributed immensely through hard work and innovations of their own—but I'll do so anyway. Early on, Seiya Uyeda showed me how much fun science can be as we worked together trying to understand the driving forces of plate tectonics. Dan Scheirer and I had several cruises together; he taught me by example how to be an organized, effective chief scientist. My students and my colleagues at Brown, especially Marc Parmentier, Karen Fischer, and Greg Hirth, have made the past 40 years delightful. My Ph.D. adviser, Frank Press, taught me to tackle important questions, to critically evaluate my own work, and to be bold and unafraid of being wrong or making mistakes. I seem to have learned this last lesson well. I've told my students that I couldn't retire until I published a paper with no mistakes, but now I have gone ahead and retired anyway. But since I expect to remain active in research for another decade or so, there is still hope.

Finally, I'd like to thank my wife, Roberta Ryan, who has tolerated my seagoing adventures and has been a wonderful partner.

—**Donald W. Forsyth**, *Brown University, Providence, R.I.*

Eric F. Wood Receives 2017 Robert E. Horton Medal

Eric F. Wood was awarded the 2017 Robert E. Horton Medal at the AGU Fall Meeting Honors Ceremony, held on 13 December 2017 in New Orleans, La. The medal is for "outstanding contributions to hydrology."

Eric F. Wood

Citation

The awarding of the Robert E. Horton Medal to Eric F. Wood recognizes him for major advances he has made toward process-based representation of global hydrology through developing hyperresolution models and enhancing them dynamically with remotely sensed observations using novel methods of data assimilation.

Eric was a pioneer in fundamental research on scaling and similarity of catchment hydrologic responses. He introduced the "representative elementary area" concept that showed that catchment response could be represented in terms of "building blocks" of some minimum size. This breakthrough launched him into the era of spatially distributed hydrologic modeling. Eric was the first to develop a distributed modeling framework that accounted for the effects of topography and land surface–atmosphere interactions involving coupled water–energy dynamics. Many of the distributed modeling concepts Eric pioneered found their way into the Variable Infiltration Capacity (VIC) macroscale hydrology model, which is the default land surface parameterization scheme in many global circulation models used in global change science.

Building on the success of distributed models at river basin scales, Eric Wood and his colleagues extended the modeling all the way to the globe and used the models to make predictions of river flows, floods, and droughts, discovering interesting regional and global patterns. At the continental and global scales, Eric made major contributions to increasing the predictability of streamflow by taking advantage of both soil moisture and precipitation data from satellites. He developed new conceptualizations of radiative transfer that allowed ingestion of radiation data directly into hydrologic models. Eric's research also showed that knowledge of initial soil moisture provides the main source of forecasting skill and that the potential for improved forecasts was limited by the accuracy of precipitation estimates. Eric's frameworks for improving predictability have been adopted by major weather forecasting centers around the world to routinely assimilate satellite estimates of land surface conditions into numerical weather prediction models. This enhanced forecast methodology has led to significantly improved drought forecasts.

Finally, through his leadership within global programs such as the World Climate Research Programme and the Global Water and Energy Experiment and his involvement with national organizations such as NASA and the National Oceanic and Atmospheric Administration (NOAA), Eric has steered global water research along his vision of global, distributed hydrology. The promise of global hydrology, deemed impossible only a few years ago, has now been realized through the efforts of Eric Wood, and he is therefore a deserving recipient of the Robert E. Horton Medal.

—**Günter Blöschl**, *Vienna University of Technology, Vienna, Austria*

Response

I'm honored that AGU selected me to receive the Robert E. Horton Medal, and I thank Professor Günter Blöschl for the kind citation that provides a summary of my contributions. Over the past 40 years many people contributed to my research—over 30 Ph.D. students, 30 postdocs and research staff, and many collaborators. While space limitations preclude listing all of them and the ways they contributed, I would like to provide a perspective on the evolution of the research summarized in the citation. In the early 1980s, Keith Beven encouraged me to think about process-based hydrologic processes that led to my "Representative Elementary Area" concept. Understanding the impact of landscape variability on water and energy fluxes has been an unresolved research problem, but the work of M. Sivapalan, W. Crow, and C. Peters-Lidard indicated that ignoring such variability leads to biased surface fluxes. Including spatial variability in land surface models led to my 30-year collaboration with Dennis Lettenmaier in the development of the Variable Infiltration Capacity model, which started with Xu Liang's Ph.D. dissertation in the early 1990s at the University of Washington. Twenty years later, I proposed the development of *hyperresolution* land surface modeling (LSM)—30 to 100 meters at continental scales—to capture this variability, which led to the development by my student Nathaniel Chaney of HydroBlocks, which we've run at 30 meters across the contiguous United States. In the mid-1990s a strategy was developed for using VIC and remote sensing from small-scale modeling (focusing on processes) to continental- to global-scale modeling (focusing on the global water cycle). With Dennis Lettenmaier and his group, we developed the first continental-scale, long-term forcing data set for LSM as part of the North American Land Data Assimilation System (NLDAS), which was used by Justin Sheffield to develop a VIC-based objective drought index and by Ming Pan to develop assimilation systems with remote sensing data. Within the NLDAS project we also used NOAA's Climate Forecast System seasonal forecasting model to develop seasonal hydrological forecasting and, recently, a multimodel forecast system with my postdoc Niko Wanders. The experience over the United States allowed us to expand to a global domain, where we now run historical and real-time flood and drought monitors as a *climate service* to help users improve their decisions. I see my Robert Horton Medal as a medal shared with all of my students, research staff, and collaborators who contributed to the work and with the NASA and NOAA program managers who funded my research. I gratefully thank them all.

—**Eric F. Wood**, *Princeton University, Princeton, N.J.*

Roberta Rudnick Receives 2017 Harry H. Hess Medal

Roberta Rudnick was awarded the 2017 Harry H. Hess Medal at the AGU Fall Meeting Honors Ceremony, held on 13 December 2017 in New Orleans, La. The medal is for "outstanding achievements in research on the constitution and evolution of the Earth and other planets."


Roberta Rudnick

Citation

Earth's crust is important to us because we happen to live on it. It also contains more than half of Earth's internal heat production, as well as most of its potassium and phosphorus. Its formation has left the residual mantle in a dramatically different state. Thus, knowing its composition is critical to any understanding of how Earth's interior works. Roberta Rudnick is the world's leading authority on the composition of the continental crust and lithosphere. Toward this end, she integrated geophysical properties of the crust with a comprehensive array of geochemical data to elucidate the role of the lower crust, which is inaccessible to direct observation. Today, if one is looking for the best estimate of the average continental crust or of its upper or lower portions, the go-to papers are those of Roberta Rudnick and her coworkers David Fountain and Shan Gao. The continental crust is welded to a much more massive subcontinental lithosphere. To elucidate the origin and evolution of this lithosphere, Roberta has conducted definitive studies on lithospheric peridotite and eclogite xenoliths, concentrating on trace element and isotope systems.

During the past several years, she has also become a leader in using one of the new, often called unconventional tracers, namely, lithium isotopes, to study near-surface continental processes such as weathering and intracrustal fluid flow, as well as recycling of near-surface continental material into the mantle. With her graduate student Fang-Zhen Teng, she demonstrated unequivocally, through detailed field and analytical work on magmatic aureoles, that reactive transport causes kinetic isotope fractionation. This work has opened up a new area of research on using kinetic isotope fractionation to constrain the timescales of diffusive and advective geochemical processes.

Most recently, together with her postdoc Richard Gaschnig and student Ming Tang, she has tackled the thorny problems posed by the long-term chemical evolution of the crust. Ancient crust is sparsely exposed and affected by weathering alteration and is thus subject to serious sampling biases. Her group dealt with both problems by analyzing ancient glacial tills, rather than sampling water- or wind-transported sediments, and developing weathering-resistant chemical proxies to show that ancient continents were richer in Fe and Mg and contained less granitic material than today's crust.

The Harry H. Hess Medal is intended to honor "outstanding achievements in research on the constitution and evolution of the Earth and other planets." Roberta's research scope and accomplishments fit that description perfectly.

—**Albrecht W. Hofmann**, *Max Planck Institute for Chemistry, Mainz, Germany; also at Columbia University, New York*

Response

I am deeply moved and humbled by this tremendous honor. Science is not an individual pursuit; it is a collaborative endeavor, whether it be from "standing on the shoulders of giants" per Sir Isaac or through joint ventures with students and fellow scientists. That is why it is just a little embarrassing to stand here as an individual to be honored for accomplishments that reflect the work of so many. For over 3 decades, Bill McDonough and I collaborated on a wide variety of projects from the crust to the mantle and had many debates (yes, zirconium can and *does* fractionate from hafnium—I think I won a bottle of red on that one). The late Gao Shan, China University of Geosciences, Wuhan, who died far too early, was one of the most creative and inspiring scientists I have worked with. Together we explored the unusual happenings of the North China Craton, which introduced me to a fascinating part of the world and opened the door to many other collaborations. I feel that Shan's enormous contributions were never adequately celebrated, and I hope that I can share this award with him posthumously.

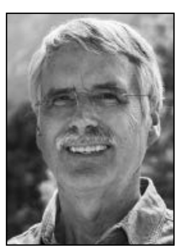
I have been fortunate to have worked with incredible students from whom I learned more than I taught. There is nothing more satisfying than to see your students go on to achieve at the highest levels: Cin-Ty Lee, Fang-Zhen Teng, Jingao Liu, Xiaoming Liu (no relation), and Ming Tang, among others, keep me in awe of their intelligence, creativity, and overall kind spirits. They have become part of my extended family. I, in turn, benefited from mentoring from quite a few folks: Ross Taylor and Scott McLennan at Australian National University introduced me to the fascinating debate about continental crustal evolution and the use of sedimentary rocks to read the record of ancient Earth. Steve Goldstein, Al Hofmann, and the late Ted Ringwood all served as important mentors post-Ph.D. I've had the good fortune to work in collaborative and supportive departments at the University of Maryland and now at the University of California, Santa Barbara.

Finally, my family has supported me every step of the way: my brother Mike and sister Linda are here tonight with their families; my 95-year-old mother (Janet Rudnick) could not make it but continues to be an inspiration. My son, Patrick McDonough, is one of the finest humans I know. I thank you all, and those whom time does not permit me to mention by name, from the bottom of my heart.

—**Roberta Rudnick**, *University of California, Santa Barbara*

Kevin E. Trenberth Receives 2017 Roger Revelle Medal

Kevin E. Trenberth was awarded the 2017 Roger Revelle Medal at the AGU Fall Meeting Honors Ceremony, held on 13 December 2017 in New Orleans, La. The medal is for "outstanding contributions in atmospheric sciences, atmosphere–ocean coupling, atmosphere–land coupling, biogeochemical cycles, climate or related aspects of the Earth system."


Kevin E. Trenberth

Citation

Kevin Trenberth is being recognized for his outstanding contributions to understanding how the climate system operates, for gaining critical insights into the nature and future of climate change, and for his unusually dedicated leadership in the climate sciences. He is also being recognized for an almost unparalleled passion for climate science debate and communication. To interact with Kevin is not only to keep on your toes, it also is to get fired up and learn.

Kevin Trenberth's scientific productivity is astonishing: He has published over 500 scientific articles and papers. He is listed among the top handful of authors in highest citations in all of geophysics, and he has a staggering h-index.

An abbreviated summary of his primary areas of contribution includes attribution of climatic events, heat budgets, data set development and climate information systems, research on the El Niño–Southern Oscillation, the water cycle, the mass of the atmosphere, and Southern Hemisphere meteorology.

Kevin has been perhaps the most significant contributor on the planet to our understanding of the Earth's energy budget—an area of inquiry that is vital to understanding climate change and climate variability. His success derives from sheer productivity combined with multiple lenses through which he learns, including foci on ocean heat content, sea level change, models, and satellite measurements. He recognizes challenges before others and invests enormous effort in solving them.

Kevin has led international teams to close the Earth's energy budget and provide robust updates to our planet's growing energy imbalance. His work on energy has also linked and quantified sensible heat, latent heat, and kinetic energy flows in the atmosphere and the processes responsible for the transports, in particular, the roles of midlatitude storms, the Hadley circulation, monsoonal circulations, and planetary-scale quasi-stationary waves. Kevin's insights go deep but also far and wide in the field of climate science.

Kevin has flown many miles in service of the climate community, and this is appreciated by more colleagues than he will ever know. Kevin is driven by passion to learn and to help society come to grips with what is happening to our climate system and why. This passion inspires as well, and Kevin has often taken the time to mentor his more junior colleagues on the ways of the climate system, ways of knowing about the climate system, and ways of communicating climate system knowledge with society.

Kevin's recent leadership in the area of climate attribution deserves special attention. His push to provide more

useful insights to policy makers builds on his heat budget expertise but also on common sense. This highlights what is driving Kevin Trenberth—to learn what must be learned and to make sure society understands the implications before it is too late. Like Roger Revelle, Kevin Trenberth has served both the scientific community and society in many ways that will long be remembered.

—**John P. Abraham**, *University of St. Thomas, St. Paul, Minn.; and* **J. T. Overpeck**, *University of Arizona, Tucson*

Response

I am thrilled and honored to receive AGU's Roger Revelle Medal. Roger was the scientist who wrote in 1957, "Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future." I was fortunate to meet him at a National Research Council workshop in November 1990, not long before he died, in July 1991. I was an invited speaker talking about climate change, El Niño, and water, and Roger asked a question about El Niño and carbon dioxide: the issue being that during El Niño, upwelling of carbon and nutrient-rich waters along the equator ceases, lowering carbon dioxide (CO_2), but is offset by more drought and wildfires over land and less uptake by warmer oceans, leading to an increase in atmospheric CO_2.

In my career, which began in New Zealand, I have always had a global perspective. I began as an atmospheric scientist but became involved at an early stage in El Niño research, which meant interacting with oceanographers, and I became what was really a first-generation climate scientist. I was privileged to become conversant in both fields and in hydrology and to see how these sciences have changed to become more global, with fewer proprietary data; instead, there is widespread data sharing and global reanalyses of atmosphere and ocean data, which I was fortunate to help develop and exploit.

I wish to especially thank the nominators; in particular, John Abraham led the effort with Jon Overpeck, plus support from Tom Karl, Mike Mann, Mike Wallace, John Kutzbach, and Warren Washington. Thanks also to Jim Hurrell, the National Center for Atmospheric Research (NCAR) director, and other NCAR colleagues and my family for their support.

Being heavily involved in the World Climate Research Programme and the Intergovernmental Panel on Climate Change and caught up in the so-called "climategate" debacle, along with Mike Mann, I was pushed toward becoming much more involved in communicating climate science to the public than is my introverted nature. Even today, many scientists, let alone the public, are not fully conversant with climate science and attribution, especially for extreme events (although I have a fan in Al Gore). With deniers in the White House and Washington, good communication about climate science has become even more important. Please join me in recognizing that science is not about beliefs, but rather is evidence driven. You might say that science trumps ideology! I am sure Roger Revelle would think so.

—**Kevin E. Trenberth**, *National Center for Atmospheric Research, Boulder, Colo.*

Brian Kennett Receives 2017 Inge Lehmann Medal

Brian Kennett was awarded the 2017 Inge Lehmann Medal at the AGU Fall Meeting Honors Ceremony, held on 13 December 2017 in New Orleans, La. The medal is for "outstanding contributions to the understanding of the structure, composition, and dynamics of the Earth's mantle and core."

Brian Kennett

Citation

Brian Kennett's innovations in theoretical seismology, as well as his profound and wide-ranging observational studies, have had a lasting impact in geodynamics and geochemistry and have significantly improved the practice at international data centers for seismology.

In Cambridge, where he obtained his Ph.D. in 1973, he developed the first method to compute complete seismograms in layered models with control of reverberations. He combined this with observational studies of seismic waves at intermediate and high frequencies—work that eventually led to the two-volume book *The Seismic Wavefield.* This is already a classic, broad in scope, encompassing near-field strong ground motions to wave propagation on a global scale. After moving to Australia, he pioneered, with Rob van der Hilst, the first continent-wide mobile array of broadband seismographs (SKIPPY).

Brian took the lead in constructing a reference Earth model that gave accurate predictions of the travel times of the seismic phases for earthquake source location. With Bob Engdahl he developed the iasp91 model and further improved this by the addition of new travel time data on core phases (ak135). These models are now used by most international organizations as standards for the routine determination of earthquake locations and by a number of research groups performing high-resolution seismic tomography using the travel times of seismic phases.

Of great importance has been his development of joint seismic tomography using the arrival times of both *P* and *S* waves to extract robust constraints on the distribution of bulk and shear moduli at depth. This work sparked an extremely productive effort among seismologists, mineral physicists, and geodynamicists to shed insight into the material nature of mantle heterogeneity. A lasting outcome from this endeavor is quantitative interpretations of 3-D Earth structure in terms of thermal and compositional variations of the mantle in their relevant phase assemblages that link seismic and geodynamic interpretations of Earth structure in a consistent way.

In addition to his scientific work, Brian has been a mentor of numerous seismologists and a leader of the international seismological community, as president of the International Association of Seismology and Physics of the Earth's Interior; editor of *Geophysical Journal International* for 20 years, *Physics of the Earth and Planetary Interiors,* and *Earth and Planetary Science Letters;* and nationally as director of the Research School of Earth Sciences in Canberra.

—**Guust Nolet**, *Université de la Cote d'Azur, Nice, France; also at Princeton University, Princeton, N.J.*

Response

It is a singular honor to be awarded the AGU Inge Lehmann Medal for the facets of my work connected with the deeper Earth. I thank my nominator, Guust Nolet, and my supporters for their efforts on my behalf.

My research has been primarily based in seismology, with both observational and theoretical components directed at the understanding of seismic wave trains. These studies have also involved occasional collaborative forays into mineral physics and geodynamics. I have tended to work on seismological results at higher frequencies with particular emphasis on fine structure within the Earth that is likely to have the closest relationships to geochemistry and petrology.

Most of this work has been undertaken at the Australian National University, where Ted Ringwood encouraged my early work on the mantle, though he did not always like the answers obtained. Thanks to the push by Anton Hales for improved seismic travel times, I collaborated with Bob Engdahl and Ray Buland on the development of models that are now used for routine location by major international agencies. With the availability of travel times that are consistent between *P, S,* and the depth phases, it is possible not only to get better locations, notably in depth, but also to generate improved phase readings that can underpin high-resolution tomographic imaging. Following reprocessing, the arrivals of both *P* and *S* waves can be exploited in joint tomography that allows the characterization of different heterogeneity regimes, as well as the delineation of major structures. With multiple images a more direct answer can be sought for the relative influences of temperature and composition.

New results frequently require a new approach. With Rob van der Hilst we established the first continent-wide mobile array in the SKIPPY experiment across Australia. Among many other results, intriguing evidence of high-frequency scattering in the inner core was brought to light in work with George Poupinet, thanks to a fortunate distribution of seismic events around Australia. Improved knowledge of shallow structure, utilizing adaptive stacking procedures and novel array designs, has also contributed to greater transparency for the influence of deep structure.

None of these efforts would have been possible without the unwavering support of my wife, Heather, my companion on a more than 40-year journey exploring the Earth in depth.

—**Brian Kennett**, *Australian National University, Canberra*

S. K. Satheesh Receives 2017 Devendra Lal Memorial Medal

S. K. Satheesh was awarded the 2017 Devendra Lal Memorial Medal at the AGU Fall Meeting Honors Ceremony, held on 13 December 2017 in New Orleans, La. The medal is for "outstanding Earth and/or space sciences research by a scientist belonging to and working in a developing nation."


S. K. Satheesh

Citation

Satheesh is a pioneer in aerosol research. He has made outstanding contributions to our understanding of the climate impact of atmospheric aerosols. He was among the first to demonstrate that there was a significant discrepancy between shortwave radiative heating at the ocean surface and the top of the atmosphere due to light absorbing aerosols. This was a significant finding since prior work had focused mostly on light scattering sulfate aerosols of anthropogenic origin. He then innovatively combined satellite data with field experiments and numerical model simulations to show that aerosols can alter the natural hydrological cycle and cloud properties. As chief mission scientist of several aircraft field campaigns, in his work he has shown the presence and the role of elevated aerosol layers that influence the onset of the Indian monsoon. These elevated aerosol layers over India show strong meridional gradients with increased aerosol warming that have implications for the amount of rainfall over this region. Furthermore, his recent work has shown that black carbon can become elevated to the stratosphere, having serious implications for ozone loss and recovery.

Satheesh continues to impress the community with his creativity by pioneering the design of a small satellite based on multiangle polarization techniques to measure and assess the role of aerosols on climate. He has also developed an angular scattering instrument to study the role of aerosol mixing that is vital for satellite and modeling studies.

Using his Aerosol-Climate Observatory in the Indian Institute of Science and the Center for Climate Excellence in Chitradurga, he trains and mentors the next generation of aerosol scientists.

As a longtime colleague, I am excited that he is the 2017 winner of the Devendra Lal Memorial Medal. His long list of awards and honors bears testimony to his hard work and diligence. Not only is he a tireless worker and a creative aerosol researcher, but also he works with astonishing humility with colleagues all around the world to solve important research problems.

I am looking forward to more exciting breakthroughs from his current and future work.

—**Sundar Christopher**, *University of Alabama in Huntsville*

Response

I am delighted to be named as a recipient of the Devendra Lal Memorial Medal and thank AGU for bestowing on me this great honor. I thank Sundar Christopher for nominating me and for the generous citation. I thank others who supported my nomination and the committee members, who assessed the value of my contributions. My research contributions were possible because of the consistent support and encouragement from my colleagues, mentors, students, and collaborators, and I would like to express my deep gratitude to all of them.

I developed my interest in atmospheric science after learning about the Earth's ionosphere during my undergraduate studies. I pursued my doctoral work at the Space Physics Laboratory, Vikram Sarabhai Space Centre, with K. Krishna Moorthy as my thesis adviser, and I am grateful to him for being an excellent mentor. I joined the laboratory with a physics background, without knowing much about the Earth's atmosphere, and learned a lot about aerosols from him. My adviser and the then director of the laboratory, B. V. Krishna Murthy, treated me like a colleague, which was a huge encouragement in shaping my career. I was a postdoc at the Center for Clouds, Chemistry and Climate (C^4), Scripps Institution of Oceanography, University of California, San Diego, under V. Ramanathan and his outstanding research team. This provided me an excellent opportunity to gain knowledge about atmospheric radiative transfer from Ram.

I joined the Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science, as a faculty member and became part of a creative academic environment. At the institute, J. Srinivasan played an important role in shaping my scientific career. I received generous support for my research from the Indian Space Research Organisation, Department of Science and Technology, Ministry of Earth Sciences, Council of Scientific and Industrial Research, and Divecha Centre for Climate Change. A 1-year sabbatical at NASA Goddard Space Flight Center with Lorraine Remer and her fantastic team was very productive. I got a rare opportunity to sharpen my knowledge on satellite remote sensing.

Finally, I am grateful to my parents and family for their support over the years. I thank my wife, Deepshikha Singh, and my son, Satdeep, for their constant support, cooperation, and encouragement.

—**S. K. Satheesh**, *Divecha Centre for Climate Change and Centre for Atmosphere and Oceanic Sciences, Indian Institute of Science, Bangalore*

The William Bowie Medal was not presented at the 2017 Fall Meeting.

The River Basin's Tale: Carbon Transport Along the Thames

London Bridge over the River Thames, circa 1870–1890. Credit: Cornell University Library

More than a decade after writing *The Jungle Book,* British novelist Rudyard Kipling penned a poem in honor of the major waterway running through London: the Thames River. "The River's Tale" speaks of modern bridges stretching across the river, young and naive in comparison to the age-old waters of the Thames. Centuries later, scientists continue to plumb the depths of the river's wisdom.

It is well known that widespread industrialization, particularly during the mid-1800s, drastically altered landscapes all over the globe. These land use changes are thought to have increased the amount of carbon being transported by rivers to the world's oceans. This phenomenon, known as "global browning," affects aquatic life, water resources, and climate.

Research suggests that much of the additional carbon entering waterways through global browning comes from soil. However, scientific knowledge of this and other possible driving factors is limited, as past studies have used mainly short-term observations from the past 50 or so years.

Rather than muddy the waters with more short-term studies, *Noacco et al.* reconstructed concentrations of carbon in the Thames River basin over 130 years using more than 20,000 samples of water color and dissolved organic carbon concentration measured at the outlet of the basin. This region, with its lowland landscape, temperate climate, mineral soil, and mix of urban and rural land uses, also provides more diversity than in past studies, which have focused mainly on rural areas.

The researchers adapted a carbon export model covering the entire United Kingdom, linking environmental properties of the Thames River basin to the release of carbon into rivers. They combined this with another model that showed the effects of land use changes on the release of carbon from soils. In concert, these models allowed them to compare the influence of various factors related to land use, climate, and population on changes in carbon levels. Then, armed with knowledge of land use and land use change history, climate, and population changes to the basin, they estimated carbon levels throughout the basin since 1884.

The team found that urbanization is responsible for close to 90% of the observed long-term rise in carbon. Urbanization led to a boom in population growth, which (by causing a major increase in the amount of liquid sewage discharged to waterways) released much more carbon than was previously believed. This urbanization was responsible for around 671,000 metric tons of carbon feeding into the basin over the 130-year period.

Shorter-term effects on carbon concentrations in the Thames, the researchers found, came from soil disturbed by land use changes. The biggest disturbance by far was World War II, during which nearly half of the grasslands in the Thames River basin were plowed to create farmland. As a result, in just a few years, 45,000 metric tons of carbon that had built up in the soil over decades were released into nearby rivers.

The basin's population, which has grown fourfold since the 1880s, continues to increase. This puts pressure on drinking water resources (the Thames currently provides two thirds of Londoners' drinking water), as well as on wastewater treatment, water quality, and river ecology. Although the researchers did not find that warming temperatures have increased carbon levels in the Thames River basin thus far, they expect rising temperatures and shrinking river flows due to climate change to further amplify these pressures.

The study develops a framework for modeling major drivers of carbon—not just in the Thames, but also in rivers around the world—and highlights the importance of urban areas in the global transport of carbon to rivers and oceans. Given that more than half of the world's population currently lives in urban areas and nearly 70% is expected to do so by 2050, the authors speculate that it may be necessary to actively protect sensitive basins from urban development because it is likely to trigger the release of even more carbon into rivers. (*Journal of Geophysical Research: Biogeosciences,* https://doi.org/10.1002/2016JG003614, 2017)

—Sarah Witman, Freelance Writer

Ocean Dynamics May Drive North Atlantic Temperature Anomalies

For at least the past 1,000 years, the surface waters of the North Atlantic Ocean have undergone a series of warmer and cooler phases, each lasting about 20–40 years and differing by a maximum of about 0.5°C. Known as the Atlantic Multidecadal Oscillation (AMO), this pattern influences Atlantic hurricanes, Arctic sea ice, and European summer climate, as well as rainfall and droughts worldwide. What's more, it can obscure or amplify the effects of global climate change.

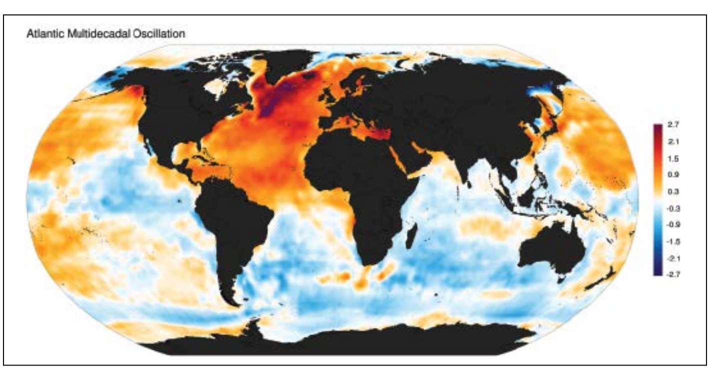
Although the AMO is well documented, the underlying mechanism that drives it is unknown and remains up for debate. In a new study, *Zhang* presents compelling findings in support of the idea that ocean dynamics play a central role in the AMO.

Past studies, including some copublished by the author, had already indicated an important role for the ocean in powering the AMO. These studies propose that large-scale ocean circulation underpins the AMO. However, ongoing debate and recent studies suggest that stochastic atmospheric white noise is the main driver of the pattern.

In an effort to settle the debate, the author investigated several decades' worth of monthly temperature and salinity observations for the surface and subsurface of the subpolar North Atlantic, the region with the most extreme temperature anomalies seen in the AMO. The author also examined the simulations using a fully coupled climate model known as Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1.

The author's analysis revealed key statistical features of the AMO that are not adequately explained by atmospheric mechanisms. Instead, she found that the key AMO features she identified are linked with the Atlantic Meridional Overturning Circulation, a major current in which warm, salty water flows northward in the upper Atlantic while colder water flows southward at greater depths. These findings lend support to the ocean dynamics mechanism.

The debate over what drives the AMO is not yet resolved. Nonetheless, the study provides compelling evidence for the important role of ocean circulation and contributes new insights into the features that characterize the AMO. (*Geophysical Research Letters,* https://doi.org/10.1002/2017GL074342, 2017) **—Sarah Stanley, Freelance Writer**



The spatial pattern of sea surface temperature anomalies associated with the AMO. Colors represent the sea surface temperature anomalies (1870–2013) regressed on the AMO index. New research suggests that the key features of the AMO cannot be explained as the direct response forced by atmospheric white noise but are consistent with the ocean dynamics mechanism. Credit: Giorgiogp2, CC BY-SA 3.0 (http://bit.ly/ccbysa3-0)

NASA Fleet Helps Predict Space Weather

The outermost layer of the Sun's atmosphere is a halo of hot gases, whose temperatures top 1,000,000°C. This formation, called the corona, meaning "crown" in Latin, can be seen using specialized instruments on Earth and in space during a total solar eclipse.

This coronal mass ejection made contact with Earth's magnetosphere in September 2012. Credit: NASA

From time to time, massive jets of plasma—infused with magnetic fields—spew from the Sun's corona, traveling hundreds of kilometers per second. When these eruptions (called coronal mass ejections, or CMEs) get close enough to Earth, they can cause spectacular auroral events and geomagnetic storms, which pose a threat to electric power grids and commercial aircraft.

In a recent study, *Möstl et al.* applied a way to better predict the time when a CME will hit Earth or another nearby planet. To do this, they looked at initial conditions that kicked off more than 1,000 CMEs, modeled when they were expected to hit Earth or another planet, and compared their modeled data to when the CMEs actually struck.

To create these hindcasts, researchers used data collected by sensors aboard NASA's Solar Terrestrial Relations Observatory (STEREO) over a period of 8 years, from 2007 to 2015. The mission is part of a larger fleet of NASA spacecraft, called the Heliophysics System Observatory, which carry instruments designed to probe various dynamics of our solar system.

About once every 11 years, the Sun's north and south magnetic poles switch, causing a flurry of geomagnetic activity. The time it takes the Sun to go from a quiet minimum state to solar maximum, when more eruptions happen, and back to solar minimum is known as the solar cycle. The period in which the instruments collected these data is about two thirds of a full solar cycle. The data provide information on the CMEs, such as their speed, their direction, and the width of the affected area.

The researchers incorporated this information into a model that allowed them to produce hindcasts of the likelihood that a CME would have encountered a planet (and, if entirely likely, what time the encounter would have taken place). They found that of all the CMEs the model would have predicted, only about a third of them were actually detected (the rest would have been false alarms).

But even though these hindcasts were far from perfect, those that were not false alarms were accurate to within about 2.5 hours (plus or minus about 17 hours) compared to the actual time the geomagnetic activity hit Earth. Furthermore, the researchers found that prediction accuracy did not decrease with the imager's distance from Earth.

This study is an important step toward understanding and predicting CMEs, an element of space weather that directly affects human life on Earth. The researchers' successful use of data to produce hindcasts of CMEs could help lead to a future satellite mission that would use specialized instruments to collect the information scientists need to monitor the space between Earth and the Sun. (*Space Weather,* https://doi.org/10.1002/2017SW001614, 2017) **—Sarah Witman, Freelance Writer**

AGU's Career Center is the main resource for recruitment advertising.

All Positions Available and additional job postings can be viewed at **https://eos.org/jobs-support.**

AGU offers printed recruitment advertising in *Eos* to reinforce your online job visibility and your brand.

Visit **employers.agu.org** to view all of the packages available for recruitment advertising.

SIMPLE TO RECRUIT

- online packages to access our Career Center audience
- 30-day and 60-day options available
- prices range $475–$1,215

CHALLENGING TO RECRUIT

- online and print packages to access the wider AGU community
- 30-day and 60-day options available
- prices range $795–$2,691

DIFFICULT TO RECRUIT

- our most powerful packages for maximum multimedia exposure to the AGU community
- 30-day and 60-day options available
- prices range $2,245–$5,841

FREE TO RECRUIT

- packages apply only to student and graduate student roles and all bookings are subject to AGU approval
- eligible roles include: student fellowships, internships, assistantships, and scholarships

- *Eos* is published monthly. Deadlines for ads in each issue are published at **http://sites.agu.org/media-kits/eos-advertising-deadlines/.**
- *Eos* accepts employment and open position advertisements from governments, individuals, organizations, and academic institutions. We reserve the right to accept or reject ads at our discretion.
- *Eos* is not responsible for typographical errors.

* Print-only recruitment ads will only be allowed for those whose requirements include that positions must be advertised in a printed/paper medium.

Atmospheric Sciences

Division Director, Division of Atmospheric and Geospace Sciences, National Science Foundation

Serves as Division Director in the Division of Atmospheric and Geospace Sciences (AGS), Directorate for Geosciences (GEO). The mission of the Division of Atmospheric and Geospace Sciences is to enable fundamental research as well as to support relevant infrastructure and education that advances understanding of the behavior of the earth's atmosphere and its interactions with the sun. Included are studies of physics, chemistry, and dynamics of earth's upper and lower atmosphere and its space environment, research on climate processes and variations and studies to understand the natural global cycles of gases and particles in earth's atmosphere. The Division also provides support for participation by the United States scientific community in international scientific research endeavors, such as the World Climate Research Program.

The Division works with individual grants and at national research facilities, including the National Center for Atmospheric Research (NCAR), and with the U.S. atmospheric sciences academic community to direct funding towards advancing the frontiers of knowledge, developing the next generation of researchers, and enhancing the public's understanding of atmospheric sciences.

The Division Director provides leadership and management to the Division's programs, assists the Assistant Director in carrying out Directorate-wide responsibilities such as the preparation of budget submission for Congress, provides oversight and management of the Division budgets, and oversees the recruitment of scientific staff. The incumbent also supervises and provides leadership and guidance to administrative and support personnel within the Division. Externally, the Division Director represents the Division in a variety of NSF-wide and interagency activities related to research and education, and in interactions with the community.

The successful candidate will possess an established record of significant achievement in research administration as well as leadership responsibility in academia, industry, or government. In addition to having a strong record of research and education accomplishments within his or her technical communities, the Division Director must be experienced and competent in technical, financial, and administrative management. He/she must work well with people, be an effective communicator, and act as a mentor to continuously develop the diversity of talent and skills of his or her colleagues at all levels.

Tenure-Track and Postdoc Positions in Dept. of Atmospheric and Oceanic Sciences, Peking University

The Dept. of Atmospheric and Oceanic Sciences of Peking University invites applications for multiple tenure-track faculty positions in atmospheric and oceanic sciences. Two positions are available in physical oceanography, particularly in the areas of ocean general circulation and dynamics, air-sea interaction and climate, ocean biogeochemical cycle, ocean model development, and satellite oceanography. Four positions are available in atmospheric sciences, particularly in the areas of climate dynamics and modeling, synoptic and meso-scale meteorology, radiation and remote sensing, atmospheric chemistry, cloud physics, atmospheric boundary layer, land-air interaction, and planetary atmospheres. All positions are at the tenure-track assistant professor level under the 'Young Qianren' or 'Bairen' programs. For exceptional cases, a more senior starting position may be considered. Recruiting is conducted semi-annually (in spring and fall), until all positions are filled. The deadline for this round of recruiting is February 28, 2018. For application qualifications, benefits, required materials, and contact information, visit http://www.atmos.pku.edu.cn/rczp/50392.htm.

Meanwhile, all disciplines of our department are hiring postdocs with different application deadlines and compensation packages; see http://www.atmos.pku.edu.cn/rczp/395.htm.

Global Environmental Change

Postdoctoral Scholar in Mapping, Monitoring, and Modeling Forest Ecosystems

Northern Arizona University seeks a postdoctoral researcher to participate in research projects focused on mapping, monitoring and modeling forest ecosystems, incorporating climate, land use, and disturbance dynamics. The successful candidate will work closely with the principle investigator (Goetz) and collaborators, using remote sensing observations, biodiversity data, and models to analyze the influence of multiple factors on forest ecosystem dynamics. The position will require processing multi-sensor imagery, primarily satellite-based but also airborne remote sensing, to derive geospatial products characterizing ecosystem properties (e.g. canopy 3D structure, composition, habitat, biomass, regrowth dynamics), partly in context of the NASA GEDI mission. The research will advance analyses of disturbance and drivers of change through time. Exploration of state-of-the-art techniques to quantify relationships between structure and diversity in tropical environments is desirable. Ability to synthesize complex infor-

mation and develop structured analyses in written and visual form is essential.

The qualified candidate should have a PhD in Environmental Science, Remote Sensing, Computer Science and/or a related discipline. Relevant qualifications include experience working with earth observation imagery, lidar data, large databases, geospatial software/ tools and advanced scripting. A strong publication record and familiarity with principles of ecosystem dynamics and macroscale conservation is highly desirable. Applications accepted through Jan. 1st, 2018.

NAU is a committed Equal Opportunity/Affirmative Action Institution.

Tenure-Track Faculty Position in Climate Change and Earth System Modeling – Vanderbilt University

Vanderbilt University and the Department of Earth and Environmental Sciences has a strong institutional commitment to recruiting and retaining an academically and culturally diverse community of faculty. Minorities, women, individuals with disabilities, and members of other underrepresented groups, in particular, are encouraged to apply. Vanderbilt is an Equal Opportunity/Affirmative Action employer.

This faculty position presents an opportunity to join a productive and collegial department at a highly-ranked R1-research university. We seek an individual aimed at the highest standards of scholarship in research and teaching at both the undergraduate and graduate (MS, PhD) levels, and who would be drawn to interact with a diverse, interdisciplinary faculty and student body in the Earth and Environmental Sciences and related fields. The position is effective for the Fall 2018 semester at the Assistant Professor level. The successful candidate will have completed the PhD by August 16, 2018.

The desired concentration of study centers on climate change and/or internal modes of climate variability that operate at inter-annual to millennial time scales and at synoptic to planetary spatial scales. Study areas could also involve related biogeochemical cycles and/or the water cycle. A strong foundation in climate modeling or earth system modeling is preferred, as well as interest or experience with both modern and ancient systems.

Applications should include a vita, a statement of research and teaching interests specific to our program, and names of at least three references (including mail and e-mail addresses and phone numbers). Select applicants will later be asked to provide student evaluations of teaching, if available. Applications should be submitted online via Interfolio at http://apply.interfolio.com/44162. Contact FacultySearchVU_EES@vanderbilt.edu for more information. Applicants can meet with VU Faculty at Exhibit Both # 909. The review of files will begin in middle December, 2017 with a final closing date of January 7, 2018.

Vanderbilt University is located in Nashville, Tennessee, a thriving state-capital city that enjoys a moderate climate, excellent parks and natural areas, a strong and varied economy, ample, and diverse food, music, and cultural opportunities.

Columbia University in the City of New York

Faculty Position in Experimental Earth Science

The Department of Earth and Environmental Sciences at Columbia University seeks applicants for a tenure-track Assistant Professor position with expertise in experimental laboratory approaches to understanding Earth materials and processes. We are open to a broad set of research topics relating to the application of chemical thermodynamics and reaction kinetics over a wide range of conditions, from the Earth's surface to its interior. The ideal candidate will conduct research that complements existing and strategic priorities of the Department of Earth and Environmental Sciences, Lamont Doherty Earth Observatory, and Columbia University, including but not exclusive to: carbon capture and storage and other climate solutions, magmatic and volcanic processes, hydrothermal systems, marine and environmental geochemistry, fluid-rock interaction, climate-life-solid-earth interactions, and natural resources.

The successful applicant is expected to develop a high-impact research program at LDEO, Palisades, NY, and demonstrate potential for strong teaching abilities at undergraduate and graduate levels. Applicants should submit a cover letter, CV, statements of teaching and research interests, and names of at least 3 references using our online site:

https://academicjobs.columbia.edu/applicants/Central?quickFind=65446

Review of applications will commence on December 18, 2017 and continue until the position is filled. Columbia University is an Equal Opportunity/Affirmative Action employer, dedicated to the goal of teaching and working in a diverse environment. We strongly encourage applications from women and underrepresented groups.

The Foster and Coco Stanback Postdoctoral Fellowship in Global Environmental Science

The California Institute of Technology invites applications for a postdoctoral fellowship in global environmental science beginning in the fall of 2018. The intent of the program is to support innovative and creative early career scientists working in global environmental science, including areas such as biogeochemistry, glaciology, paleo-climatology, and the atmosphere and ocean sciences.

The fellowship is funded in part by an endowment provided by Foster and Coco Stanback. It carries an annual stipend of $62,000 plus a research expense fund of $5,000 and $2,000 in travel costs to Pasadena. The duration of each appointment is normally two years, contingent upon completion of the Ph.D. degree and good progress in the first year. The Stanback Fellow will be hosted by one or more professors, who will also provide financial support in the second year. Fellows are eligible to participate in Caltech's benefit programs, including health and dental plans.

Materials in support of an application should include curriculum vitae, list of publications, a one-page statement of research interests, and three letters of reference. To be eligible, candidates should have received their Ph.D. no earlier than April 1st, 2017 except in exceptional circumstances. All applications and references are due by January 31, 2018.

Fellowship candidates will automatically be considered for other available postdoctoral positions at Caltech in their fields of interest. Applications can be submitted at: https://applications.caltech.edu/job/stanback.

If there are any questions during the application process, please contact Jen Shechet at shechet@gps.caltech.edu

We are an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, or national origin, disability status, protected veteran status, or any other characteristic protected by law.

Interdisciplinary

Assistant Professor of Crustal Dynamics at the University of Wyoming, Department of Geology & Geophysics.

The University of Wyoming Department of Geology & Geophysics invites applications for a tenure-track, Assistant Professor position in Crustal Dynamics. The successful candidate will be expected to build a vibrant, extramurally funded research program in the broadly defined area of crustal processes and contribute to the teaching mission of the department. We seek applicants who complement existing research strengths within the department and across the university. Research focus is open including, but not limited to, lithospheric deformation, basin analysis, Earth surface processes, and the interplay of crustal processes with the biosphere or atmosphere. We particularly encourage applicants who address questions from the grain scale to the global scale and who integrate field, theoretical, experimental, and/or modeling approaches.

The department comprises 26 faculty across a range of modern geoscience disciplines with access to exceptional laboratory, field, and computational resources that support cutting-edge research including: Materials Characterization Laboratory, Geochemical Analytical Laboratory, Wyoming Center for Environmental Hydrology and Geophysics, Wyoming High Precision Isotope Laboratory, Stable Isotope Facility, Cosmogenic Nuclide Laboratory, Wyoming High-Performance Computing Center. More information about the Department can be found at http://www.uwyo.edu/geolgeophys/.

The complete announcement and the online application can be found at https://tinyurl.com/UWyoGeoJob1.

Review of applications will begin on January 5, 2018. Direct inquiries to Brandon McElroy, bmcelroy@uwyo.edu.

Cluster Hiring in Geo-Bioinformatics/Environmental Genomics and Organic Biogeochemistry, SUSTech, Shenzhen, China

The Southern University of Science and Technology (known as SUSTech or SUSTC) (http://www.sustc.edu.cn/en) was founded in 2011 with public funding from Shenzhen, a dynamic city that has been viewed as the vanguard of China's development in science and technology. The goal of SUSTech is to become a top-tier international university that excels in interdisciplinary research, talent development and knowledge discovery.

Sitting at the mouth of the Pearl River flowing to the South China Sea, the newly born (2015) Department of Ocean Science and Engineering at SUSTech aims to become a major player in education and research in ocean sciences in China. It will be housed in a

brand new building on the beautiful SUSTech campus, with ample laboratory space that is equipped with the latest technology for conducting cutting edge research. The 5000 ton R/V *Shenzhen* is in the planning stage of construction, which is expected to be built by 2022.

The Institute for Geo-Omics Research (TIGOR) at SUSTech aims to become an open platform for world class research in microbial oceanography and geomicrobiology, and an inviting home for domestic and overseas scientists to exchange ideas and together advance the field of ocean sciences. In the early stage of TIGOR's growth, the priority will be to build two research strengths: Geo-Bioinformatics/Environmental Genomics and Organic Biogeochemistry. The integration of these strengths will allow us to study systematically the evolution of life on early Earth, microbial ecology impacted by human activity, mechanisms of bio-organic interactions in the deep ocean, and fundamentals of biogeochemistry (e.g. lipid biosynthesis and bio-fractionation of isotopes of life-essential elements).

In Geo-Bioinformatics/Environmental Genomics hiring, we seek highly qualified candidates (at the assistant or associate professor levels) who are able to apply bioinformatics techniques (metagenomics, multi-omic integrative analysis, in silico lead discovery from microbial metabolites and computational biology algorithm/server development) to analyze data from the next-generation sequencing and other high-throughput sequence profiling to address fundamental questions mentioned above. Candidates with strong ecological backgrounds are particularly encouraged to apply.

In Organic Biogeochemistry hiring, we seek highly qualified candidates (at the assistant, associate or full professor levels) with strong skills in mass spectrometry and isotope geochemistry. The candidates are expected to apply GC-MS, LC-MS (Orbitrap or ion mobility Q-TOF), FT-ICR MS, or AMS to address questions mentioned above.

Highly competitive salaries and benefit packages will be provided to the hired candidates, who may also be eligible for additional government support such as the Shenzhen City's Peacock Program and the Chinese Government's One Thousand Talents Program (http://www.sustc.edu.cn/en/faculty_en).

Applicants are required to have a Ph.D. degree in earth sciences, biology, chemistry, computer science, or related disciplines. Post-doctoral experiences are preferred but not required. Candidates must have a proven and consistent track record of high-quality scientific publications and good communication skills. Chinese and English are required languages for teaching. To apply, please submit the following material electronically to wangy9@sustc.edu.cn: 1) Cover letter; 2) Curriculum vitae (with a complete list of publications); 3) Statement of research and teaching interests; 4) Reprints of three recent papers; and 5) Names and contact information for three references. All positions remain open until filled.

The Department of Marine Geosciences at University of Miami seeks an Environmental Geoscientist

The Department of Marine Geosciences (MGS) at the Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami (UM), seeks outstanding candidates for tenure track positions at either the assistant or associate professor level. We are seeking to hire into two areas, as follows.

First, geodesy, geodynamics and geophysics. We are interested in candidates accomplished (1) in measuring or modelling of sea level changes, a field of direct relevance to Miami, or (2) in the wide field of active geological processes and hazards. Teaching ability in numerical modelling methods, hydrogeology, petrology or structural geology will be viewed favorably. The successful candidate is encouraged to interact with the Geodesy and Seismology group and/or the Center of Computational Sciences. We encourage applications from candidates using NASA's forthcoming Earth Observation missions (including cryosphere).

For the second position we seek a candidate researching the geological evolution of the global carbon cycle and past climate. Central to this discipline is analysis of the interaction between the carbon cycle and other critical elemental systems, such as sulfur, nitrogen, oxygen, and key nutrients. Teaching ability in the themes of Earth materials, environmental geochemistry, and geobiology will be viewed favorably. The University of Miami offers a unique tropical location and the opportunity to integrate biological and physical oceanographic expertise into process-oriented geological research through collaboration with faculty in the Departments of Marine Biology and Ecology and Ocean Sciences. The successful candidate is encouraged to interact with current faculty in the Comparative Sedimentology Laboratory, a center with a long tradition of excellence in research and training in carbonate sedimentology which hosts a vibrant student population.

Candidates for these positions will be expected to develop vigorous, externally funded research programs, supervise students, and participate in the teaching mission of the Department and the School at both the graduate and undergraduate levels.

Questions should be directed to Sam Purkis, Chair of the Department of Marine Geosciences (spurkis@rsmas.miami.edu) and applications should be made to the Chair of the

NASA AMES RESEARCH CENTER IS SEEKING
A DEPUTY DIVISION CHIEF IN EARTH SCIENCE

Do you have a strong desire to lead, inspire and develop people? Do you want your career to leave an enduring impact on others? Do you have a passion for exploration? If you answered yes, we want you! At NASA, the key to our success is our people. We recognize the vital role that supervisors play to empower our diverse workforce to achieve our shared goals. At NASA, supervisors must have a unique combination of technical competence, individual energy, and the ability to connect with and motivate others. In return, we offer a range of missions and people to support, where you'll have the opportunity to contribute to work that matters while helping us create and sustain an environment that fosters connection, engagement, teamwork and innovation. Together, we are part of something bigger than ourselves.

The Earth Science Division at Ames Research Center in Silicon Valley is a dedicated and innovative team of about 100 scientists, engineers, and project managers that conduct observations and perform modeling and analysis in support of the NASA Science Mission Directorate. The Division includes globally recognized leaders in airborne science and field campaign management, instrument development, ecosystem and atmospheric modeling and analysis, and applications for societal benefit. Earth system science research at Ames is the foundation for the Division's leadership in new capabilities, such as high-performance computing and machine learning for large-scale Earth observation studies, unmanned aircraft systems, and small satellites. The Division's scientists use airborne and satellite-based observations and process models to address hypothesis-driven science objectives with core areas of expertise including carbon cycle and coastal/ocean ecosystems, biogeochemical cycling, atmospheric chemistry and dynamics.

The **Deputy Division Chief** supports Division operations and provides scientific and technical leadership in atmospheric and biospheric science. The Deputy works closely with the Division and Branch Chiefs to manage operations, cultivates existing and new scientific and/or technical research activities aligning with NASA Earth science focus areas, and forecasts and plans for Division priorities under the direction of Center and Headquarters management.

This position is a permanent civil service assignment as a GS-14/15 or -15.

NASA is soliciting qualified respondents to this solicitation through **usajobs.gov**. Interested applicants should apply directly to USAJobs to vacancy number **AR18D0008** at **https://nasajobs.nasa.gov/**.

US Citizenship is required.

NASA Ames Research Center does not discriminate in employment on the basis of race, color, religion, sex, national origin, political affiliation, sexual orientation, gender identity, marital status, disability and genetic information, age, membership in an employee organization, or other non-merit factor.

Search Committee, Guoqing Lin (glin@rsmas.miami.edu).

Applications will only be accepted electronically. The positions will remain open until filled.

The University of Miami is an equal opportunity employer.

Assistant/Associate/Full Professors-Physical and biological Oceanography, marine geophysics/geology – SUSTech, Shenzhen, China

The department of oceanography at the Southern University of Science and Technology of China (SUSTech) invites applications for tenure-track (or tenured) faculty positions at the ranks of Assistant, Associate, and Full Professors. Applicants must have earned doctoral degrees in marine geophysics/geology, physical oceanography, biological oceanography and ocean engineering or closely related fields. Successful applicants will be expected to establish a robust, externally funded research program and demonstrate strong commitment to undergraduate and graduate teaching, student mentoring, and professional services. These positions will remain open until filled.

SUSTech is a young university at Shenzhen, China (next to Hong Kong) since 2010 which is set to become a world-leading research university, to lead the higher education reform in China, to serve the needs of innovation-oriented national development and the needs of building Shenzhen into a modern, international and innovative metropolitan. These positions are created with a significant development to establish a vigorous research program in oceanography at SUSTech to serve the national call for China's important role in deep sea research and resource-oriented exploration in the world oceans.

To apply send a cover letter, complete vitae with list of publications, and three names of references to hiring@sustc.edu.cn, or to Dr. Y. John Chen, Chair Professor at Department of Oceanography, Southern University of Science and Technology, No 1088, Xueyuan Rd., Xili, Nanshan District, Shenzhen, Guangdong, China 518055.

Laboratory Operations Supervisor

- Leidos – Antarctic Support Contract (ASC)
- Denver, CO and Antarctica

Leidos provides logistical and science support to the National Science Foundation (NSF) US Antarctic Program (USAP).

Supervisor of Laboratory Operations for the Crary Science and Engineering Center (CSEC) at McMurdo Station, Antarctica.

The CSEC is a 46,500 ft2 multipurpose laboratory and office facility supporting a range of scientific disciplines (analytical chemistry, microbiology, microscopy, molecular biology, radioisotope and general use laboratories, seawater aquaria)

Primary Responsibilities:

- Manage office, aquarium, laboratory, staging space
- Manage budget, procurements, sub-contracts, scheduling
- Assist in hiring/supervising laboratory staff
- Manage usage, maintenance, disposal of CSEC instruments, equipment & facility safety systems
- Serve as ASC subject matter expert for laboratory practice and equipment
- Foster relationships within ASC, and with NSF, scientists
- Facility safety

McMurdo: Deploy for summer season (October – February) as on-site POC and supervisor for CSEC

Denver: Hire staff. Remote oversight of CSEC winter lab assistant.

Coordinate seasonal planning with scientists, ASC, NSF. Coordinate procurements. Allocate laboratory resources. Assist budget, long range investment planning.

Requirements:

- BS or MS in natural or physical sciences.
- 4+ years laboratory technical work
- Laboratory management experience
- Good verbal communication, computer and problem solving skills

Preferred Experience:

- Remote field work
- Polar experience
- Direct support to science research projects
- Purchasing/budget tracking
- Supervision
- Coordination of facility maintenance & access control systems

NOTE:

- Willingness and ability to deploy to Antarctica for extended periods required
- Must successfully complete physical, dental examinations as required by the NSF for deploying to Antarctica
- US citizenship or US Permanent Residency required

For more information on this role please contact Esther Hill 650-279-3427

ASSISTANT PROFESSOR, BIOGEOCHEMISTRY
The University of Wyoming

The University of Wyoming invites applications for a tenure-track, **Assistant Professor** position in Biogeochemistry in the Department of Geology & Geophysics and the interdepartmental Program in Ecology. The successful candidate is expected to build a strong extramurally funded research program in biogeochemical processes and analyses. The research focus may range broadly including topics such as microbial processes, weathering, ecosystem stoichiometry, organic geochemistry, and global elemental cycles. The University maintains facilities that support high-performance computing, stable isotope analyses, scanning electron microscopy, organic geochemical techniques, and DNA analyses.

Review of applications began **Nov. 13th** and will continue until the position is filled. Additional details and links to the application process are available **http://www.uwyo.edu/epscor/microbial-ecology/facsearches.html**.

Please apply to Job 9150 at **jobs.uwyo.edu**.

Faculty Positions available in the School of Environmental Science and Engineering, SUSTech, Shenzhen, China.

The Southern University of Science and Technology (known as SUSTech or SUSTC) (http://www.sustc.edu.cn/en) was founded in 2011 with public funding from Shenzhen City. A thriving metropolis of 20 million people bordering Hong Kong, Shenzhen has often been referred to as the 'Silicon Valley of China' with strong telecommunication, biotechnology and pharmaceutical sectors. The goal of SUSTech is to become a top-tier international university that excels in interdisciplinary research, talent development and knowledge discovery. English is the language of instruction.

The School of Environmental Science and Engineering at SUSTech was established in May 2015 to provide a new platform for performing cutting-edge research and for training a new generation of environmental scientists, engineers and managers who are interdisciplinary, innovative and global-thinking. Currently the school has 18 full time faculty members (http://ese.sustc.edu.cn/en/) with 30 or more tenure-track/tenured positions to be filled. In addition to a generous startup package to each tenured or tenure track faculty position, the school was recently awarded a 3-year grant of 50 million RMB (~7 million USD) to strengthen its 5 core areas of research. Moreover, the school is in line to receive 120 million RMB (~18 million USD) for research instrument capability development.

Applications are invited for faculty positions at all ranks. Areas of interest include, but are not limited to, water pollution and treatment, environmental (soil, groundwater, ecosystem) remediation and restoration, hydrology and water resources engineering, biogeochemistry, environmental microbiology, atmospheric chemistry, air pollution control, air quality engineering, solid waste treatment and utilization, environmental health risk assessment, environmental health interventions, remote sensing of the environment, global change, and environmental management. Highly competitive salaries and benefit packages will be provided to tenure-track/tenured faculty. New hires may be eligible for additional government support such as the Shenzhen City's Peacock Program and the Chinese Government's One Thousand Talents Program (http://www.sustc.edu.cn/en/faculty_en).

Applicants are required to have a Ph.D. degree in environmental science and engineering, earth and atmospheric sciences, or related disciplines. Post-doctoral experiences are preferred but not required. Candidates must have a proven and consistent track record of high-quality scientific publications and good communication skills. Chinese language skill is a plus but not required. To apply, submit the following materials electronically to iese@sustc.edu.cn: 1) Cover Letter; 2) Curriculum Vitae (with a complete list of publications); 3) Statement of research and teaching interest; 4) Selected reprints of three recent papers; and 5) Names and contact information for five references. All positions remain open until filled. For additional information, contact Xiaoli Wang, Email: wangxl@sustc.edu.cn, phone: +86-755-8801-0821.

Postdoctoral Positions in Ocean, Atmosphere and Climate Dynamics, Yale University

One or two postdoctoral positions in Ocean, Atmosphere and Climate Dynamics will be available at Yale University, Department of Geology and Geophysics (http://people.earth.yale.edu/profile/alexey-fedorov/about). General fields of research include ocean and atmosphere circulation, ocean-atmosphere interactions, the role of ocean in climate, climate variability and change, paleoclimate. Two particular topics of interest are (1) El Niño and mean tropical climate, and (2) stability, variability and predictability of the Atlantic meridional overturning circulation (AMOC). The work will involve numerical modeling, analyses of observational and GCM data, and analytical approaches. A PhD

in physical oceanography, atmospheric sciences or related disciplines is required. Previous experience with ocean, atmospheric or climate GCMs is highly desirable. Funding is currently available for two to three years. Successful candidates can begin their program at Yale in winter-spring of 2018; later starting dates can also be discussed. The applicants should email his/her CV, a statement of research interests, one reprint or preprint, and the names of three referees to Professor Alexey Fedorov (alexey.fedorov@yale.edu; subject: postdoctoral search). Shortlisted candidates will be contacted. Yale University is an affirmative action/equal opportunity employer. Yale values diversity in its faculty, staff, and students and strongly encourages applications from women and members of underrepresented minority groups.

Postdoctoral Research Associate Position University of Washington, Seattle, WA

(JISAO) seeks three postdocs researching atmospheric science, oceanography, climate science, and fisheries science and management. JISAO encompasses a range of scientific interests including large-scale atmospheric-ocean interaction, ocean/atmospheric dynamics, biogeochemical cycles, ocean acidification, marine ecosystems, climate impacts on ocean and land ecosystems, high-latitude climate, paleoclimate, ocean/atmospheric model development and evaluation, and climate forcing and feedbacks, including both aerosol and clouds. JISAO operates jointly between the UW and NOAA research laboratories in Seattle, particularly the Pacific Marine Environmental Laboratory (PMEL).

Terms of appointment are for one year, renewable for a second year. Positions are not project specific; applicants define research within JISAO programs and are strongly encouraged to collaborate with UW and PMEL scientists. Applicants who demonstrate research relevance to both JISAO and PMEL programs are preferred. Successful applicants must hold a recent Ph.D. to assume a postdoc.

Applicants submit electronically: curriculum vitae, publication list, brief research proposal (no more than 5 pages, double-spaced, excluding bibliography and figures) describing research to be pursued during a two-year tenure, and names of four individuals for letters of reference. A letter of support from a mentor at UW or PMEL is strongly encouraged. Research mentors may be JISAO research scientists, PMEL research scientists, and/or UW faculty members in relevant departments. Mentors can be found at [http://jisao.washington.edu/research/postdocs].

Applications should be received prior to January 19, 2018. Applications received after that date are not likely to be considered. See online ad for further information about submission.

Research Position in Modeling and Understanding the Observed Arctic Sea Ice Decline in Recent Decades, Princeton University

The Atmospheric and Oceanic Sciences Program at Princeton University in cooperation with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) seeks a postdoctoral or more senior scientist for research related to modeling and understanding of the rapid decline of Arctic sea ice observed over the satellite era. The position will be focused on improved understanding of the mechanisms causing the observed ice decline using coupled climate models and observations. The research will explore the response of Arctic sea ice to anthropogenic forcings, natural forcings, and natural decadal/multidecadal variability. Both recent graduates and more senior candidates will be considered for this position.

The selected candidate will have a Ph.D. in a related field and one or more of the following attributes: (a) a strong background in climate/ocean/sea ice dynamics (b) experience using and analyzing coupled climate models and (c) strong diagnostic skills in analyzing simulated and observed data sets. Appointments are initially for one year with renewal for an additional year based on satisfactory performance and continued funding.

Successful candidates will be based at GFDL in Princeton, New Jersey. For further information, please contact Rong Zhang (Rong.Zhang@noaa.gov) or Tom Knutson (Tom.Knutson@noaa.gov). Complete applications, including a CV, publication list, three references in order to solicit letters of recommendation, and a one-to-two page statement of research interests must be submitted to https://www.princeton.edu/acad-positions/position/5021 by December 31, 2017 to ensure full consideration, though evaluation will be ongoing. Review of applications will begin as soon as they are received, and continue until the position is filled. This position is subject to the University's background check policy.

Princeton University is an Equal Opportunity/Affirmative Action Employer and all qualified applicants will receive consideration for employment without regard to age, race, color, religion, sex, sexual orientation, gender identity or expression, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Science Planner

- Leidos – Antarctic Support Contract (ASC)
- Alexandria, VA (short Antarctic deployment)

Leidos provides logistical and science support to the National Science Foundation (NSF) US Antarctic Program (USAP).

Science Planners work directly with NSF, scientists, ASC staff to understand science projects, define requirements, minimize risk for USAP science deploying to Antarctica. Planners analyze logistical needs, develop logistical plans, manage or assist execution, track the evolution of a project.

The ideal candidate will have experience in Antarctic or other remote location science logistics, project management, and/or field data collection and be familiar with USAP operations.

Primary Responsibilities

- Review Antarctic science proposals for logistical requirements; determine appropriate support method, feasibility
- Work with scientists to develop, document logistical plans; identify risks, opportunities; ensure logistical support matches requirements
- Support long-range planning
- Communicate, interact with NSF, internal groups, scientists, military, other agency officials, international partners professionally
- Occasional Antarctic deployment
- Ensure compliance with applicable laws, regulations, standards, codes imposed by the Antarctic Treaty and U.S. Government
- Ensure safety is the highest priority

Requirements:

- BA/BS degree in science or engineering; at least 5 years relevant experience. (Note, we recruit candidates in all physical, natural sciences,)
- Prior experience with science support in remote environments.
- Familiarity with field science; field experience or science training
- Ability to review proposals for logistics, feasibility.
- Strong organizational, team, communications skills; flexible
- Microsoft Office, technical writing
- Must successfully complete physical, dental examinations as required for Antarctic deployment
- US citizenship or Permanent Residency required

Preferred :

- Prior polar field experience; science support experience relevant to USAP research

For more information on this role please contact Esther Hill 650-279-3427

Visiting Faculty Position– Volcanology and Geothermal Sciences, Kyoto University, Japan

Kyoto University invites applications for a visiting Professor or Associate Professor in volcanology, geothermal sciences and related disciplines. The successful applicant is expected to work at Aso Volcanological Laboratory or Beppu Geothermal Research Laboratory, Kyushu, Japan. Attractive salary and traveling expenses are provided from the university.

The position is opened on October 1, 2018, and the tenure is 3 to 12 months by September 30, 2019. The applicant should be 65 years old or younger when his/her term in this position has terminated.

Send (1) CV including date of birth, nationality and publication list, (2) statement of research interests, (3) pdf files of 3 significant publications, (4) names and e-mail addresses of three references and (5) desired arrival and departure date, and place of assignment (Beppu or Aso) to Prof. Takahiro Ohkura through e-mail to VFP18*vgs.kyoto-u.ac.jp (please replace "*" with "@" in the e-mail address) by March 1, 2018.

For the details, please look at http://www.vgs.kyoto-u.ac.jp/igse/e-visiting_faculty_position.html.

Inquire in advance to a member of Aso or Beppu is encouraged.

Near Surface Geophysics

The Department of Geosciences within the College of Arts and Sciences Seeks Candidates for Assistant / Associate Tenure Track Professor – Western Michigan University

Qualifications: The candidate must possess an earned Ph.D. in the geosciences or a closely-related field from an accredited institution by July 1, 2018. The successful candidate will have a demonstrated record of high-quality research, and show potential for excellence in teaching.

Responsibilities: Responsibilities of the new faculty member include: (i) generating and managing a robust, externally-funded, research program, (ii) publishing in high-quality, peer-reviewed scientific journals, (iii) teaching undergraduate and graduate courses, and (iv) contributing to the success of a campus initiative on the applications of unmanned aircraft systems in geological and environmental sciences. The tenure track, Assistant or Associate Professor, alternate academic year, will be expected to engage in geophysical research and teaching (e.g., gravity, magnetic methods, electrical methods, ground penetrating radar, and/or seismic imaging). Research expertise in the use of aerial or satellite geophysical data to interpret geological or hydrological processes will be given special consideration.

Department: The Department of Geosciences, which is comprised of 13 faculty members, is research-active and nationally-ranked. The department confers B.S., M.A., M.S. and Ph.D. degrees. The strengths of the department include hydrogeology, geochemistry, remote sensing, glacial geology, and sedimentary geology as well as environmental and resource analysis. A new initiative is underway to develop educational programs on the applications of unmanned aircraft systems (UAS) in geophysical and environmental sciences. Housed within the department is the Michigan Geological Survey, which supports and advocates for programs of applied research within the State of Michigan. The Michigan

Geological Repository for Research and Education, an important departmental component, houses a variety of subsurface samples and data related to both hydrocarbon and water resources in the region. The Department of Geosciences is located in Kalamazoo, Michigan, with some research and teaching conducted at the WMU campus in Punta Gorda, Florida. Learn more about the Department of Geosciences at http://wmich.edu/geology/. Interested individuals are encouraged to meet departmental faculty at the forthcoming AGU Fall meeting.

Western Michigan University: Western Michigan University (WMU), located in Southwest Michigan, is a vibrant, nationally recognized student-centered research institution with an enrollment of nearly 25,000. WMU delivers high-quality undergraduate instruction, has a strong graduate division, and fosters significant research activities. The Carnegie Foundation for the Advancement of Teaching has placed WMU among the 76 public institutions in the nation designated as research universities with high research activities.

Salary: Competitive and commensurate with qualifications and experience, with an excellent benefits package,

Expected Start Date: July 1, 2018

Application Deadline: Review of applications will begin January 12, 2018 and continue until the position is filled.

Please visit wmich.edu/hr/jobs for detailed information and application procedures.

Required application documents: Faculty Credential Summary; a letter describing qualifications, accomplishments, and professional experiences related to the position, and comprehensive vita; names, titles, postal and e-mail addresses, and telephone numbers of three references.

WMU is an Equal Opportunity/Affirmative Action Employer. Minorities, women, veterans, individuals with disabilities, and all other qualified individuals are encouraged to apply.

Ocean Sciences

The Department of Mechanical Engineering and the Interdepartmental Graduate Program in Marine Science (IGPMS) at the University of California, Santa Barbara invite applications for a fulltime faculty position at the tenure-track Assistant Professor level, with an anticipated start date of July 1, 2018, or later.

The Department is looking for exceptional individuals with a particular emphasis on fluid mechanics in marine environments with potential applicability to ocean energy.

Responsibilities include teaching at the undergraduate and graduate levels, recruitment, and supervision of graduate students, and the development of an actively funded research program of the highest quality. Applicants must have a PhD or equivalent degree in Mechanical Engineering or in a related field by the time of employment. A demonstrated record of excellence in research and proven ability as, or potential to develop into, an outstanding teacher are essential. Successful candidates will have a strong record of collaborative, interdisciplinary research, contribute to IGPMS' curricula and student mentoring, and leverage synergies across UCSB.

For detailed application instructions, visit: http://apptrkr.com/1109579

The department is especially interested in candidates who can contribute to the diversity and excellence of the academic community through research, teaching, and service.

The University of California is an Equal Opportunity/Affirmative Action Employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Tenure-track Faculty Position in Oceanography

The Institute of Oceanography, National Taiwan University (IONTU), invites applications for one or two faculty position(s), at the level of assistant professor or higher, starting on August 1, 2018. Applicants should hold a doctoral degree in research fields related to marine sciences, including physical oceanography, chemical oceanography, marine geology & geophysics, marine biology/fisheries or biological oceanography. Applicants should send (1) curriculum vitae (including publication list), (2) PDF reprints of up to three representative publications (published after June, 2014), (3) a proposal for future research and teaching preferences, via e-mail before January 21, 2018 to:

Prof. Yu-Heng Tseng

Chair, Faculty Search Committee

Institute of Oceanography, National Taiwan University (tsengyh@ntu.edu.tw; please also Cc to chienchung@ntu.edu.tw) Tel: +886-2-3366-1374 Fax: +886-2-2362-6802

Please visit http://www.oc.ntu.edu.tw for general information of IONTU.

Please also arrange for three recommendation letters to be sent directly to the Chair of the Faculty Search Committee. Upon receipt of the application, an acknowledgement email will be sent to the applicant within a week. Applicants who do not receive the acknowledgement email please contact the Chair of the Faculty Search Committee for confirmation.

Solid Earth Geophysics

Thomas Vogel Endowed Professorship in Geology of the Solid Earth, Michigan State University

The Department of Earth and Environmental Sciences at Michigan State University is seeking an outstanding faculty candidate to fill the Thomas Vogel Endowed Professorship in Geology of the Solid Earth at the full professor rank with tenure. Exceptional candidates at the associate professor level may also be considered. This position contributes toward our mission of expanding upon a vigorous, internationally recognized Solid Earth program at MSU, serving to complement our dramatic growth in geophysics over the past few years.

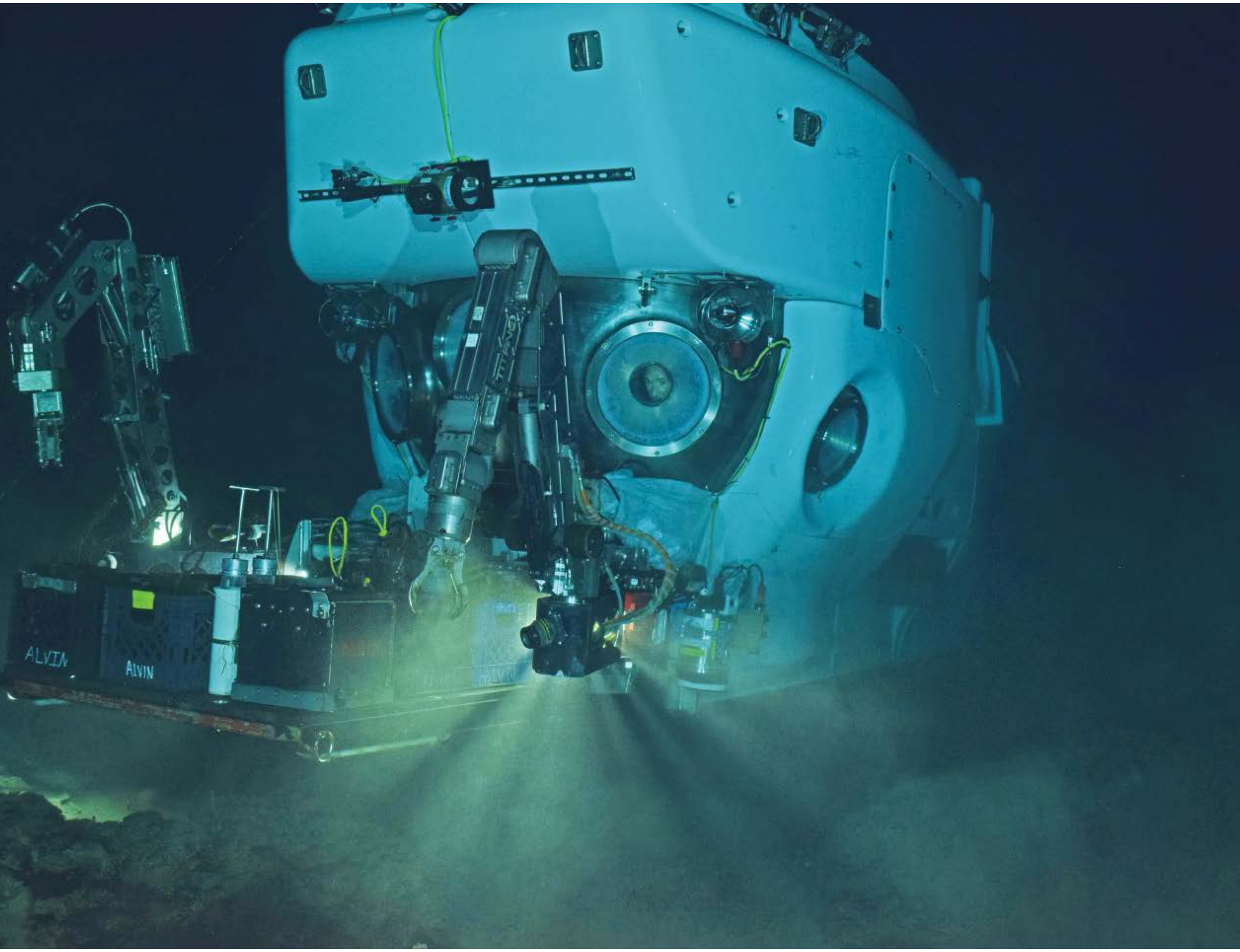
The position is broadly defined as Solid Earth, and we invite applicants with broad areas of expertise including, but not limited to, geochemistry, geophysics, geochronology, petrology, and lithospheric dynamics. Particular interest will be given to candidates with research that complements our current research growth and strength in igneous petrology and geochemistry, mineral physics, geodynamics, and seismology. The successful applicant for this position will be expected to leverage substantial annual endowed resources that come with the professorship toward developing and maintaining a strong externally-funded research program. The successful applicant will also be expected to mentor and advise graduate students and postdoctoral scholars, teach undergraduate and graduate courses, and contribute toward maintaining our collegial, cohesive, and collaborative departmental environment.

A Ph.D. in Geological Sciences, Geophysics, Geochemistry, or related field is required. Applicants are expected to be leaders in the Solid Earth community and must have well-funded research programs and an exemplary record of scholarship. Although initial review of applications will begin on January 2, 2018, new applications will continue to be considered until the position is filled. Interested applicants should upload one PDF document that includes all the following: a cover letter, CV (including names and contact information for five references), and statements of research interests and teaching philosophy. Instructions for applying can be found on www.careers.msu.edu. Posting# 478215.

Questions about the position can be sent to the Search Chair, Allen McNamara, at allenmc@msu.edu. Applications and queries will be handled in as confidential a manner as possible.

MSU is an affirmative action, equal opportunity employer and is committed to achieving excellence through diversity. All qualified applicants will receive consideration without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law. We endeavor to facilitate employment assistance to spouses or partners of candidates for faculty and academic staff positions.

Postcards from the Field



Hello!

That's me looking out DSV *Alvin*'s viewport on Dive 4850 near the summit of Matthew seamount, in the northeastern Pacific, in November 2016. I'm at a depth of approximately 2,650 meters, studying seafloor volcanic processes and magmatism as part of a National Science Foundation–Division of Ocean Sciences funded research cruise with collaborators from numerous U.S. institutions and co-principal investigators Trish Gregg (University of Illinois at Urbana-Champaign) and Mike Perfit (University of Florida, Gainesville). Possibly the deepest selfie ever taken!

—Daniel Fornari, Woods Hole Oceanographic Institution, Woods Hole, Mass.

View more postcards at
http://americangeophysicalunion.tumblr.com/tagged/postcards-from-the-field.